DANCEY

An Experimental Determination
Of the Temperature of
The Mercury Arc

Physics

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AN EXPERIMENTAL DETERMINATION OF THE TEMPERATURE OF THE MERCURY ARC

BY

LLOYDE SLOTE DANCEY, B. A.
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THESIS

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

LLOYD SLOTE DANCEY

ENTITLED THE TEMPERATURE OF THE MERCURY ARC

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Arts in Physics

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Introduction.

The problem of efficient light production is to produce the most light with the least consequent development of heat. The way for the solution of this problem is opened in the carrying of electricity through gases, for theoretically there is no limit to the efficiency of a luminescent vapor.

The gas is the most efficient the lower its temperature,(1) and the heat produced is merely a by-product. This is just the reverse of a solid incandescent body, for, while heat makes a solid incandescent it increases the pressure of a gas but does not make it incandescent. The heat put into a gas does not reappear, to any extent, in an increased vibration of the molecules but it causes them to move faster in their rectilinear paths and they, in turn, cause an increase in pressure by striking the boundary at a higher velocity. Although vibrations in a gas are not produced by heat they may be produced by making the gas the conductor of an electric current. In which case the vibrations are at a definite rate and give line spectra.

Mercury vapor vibrates at that frequency which gives its characteristic light whether the temperature is high or low and the wave length does not change as it does with the radiation of a solid incandescent body. While in the case of the solid incandescent body the wave length is determined by the temperature, in mercury vapor the wave length is fixed by the nature of the molecule and not by the temperature. The temperature effects the

(1) American Ins. of Elec. Engineers. Vol. 25, p. 798.

vibrations only to the slight extent in which vibrations small or non existing at low temperatures, may become more prominent at higher temperatures. The extreme efficiency of mercury vapor lies in a very large percentage of the total energy being radiated within the visible range. In carbon vapor this percentage of energy in the visible range is very small. It is possible theoretically to bring all the vibrations within the visible range in which case we have a perfect lamp.

The mercury arc, which is simply mercury vapor made luminous by the passage through it of an electric current, is highly efficient as compared with other kinds of electric lights; its lack of red rays, however, and consequent unpleasant coloration of objects have prevented its use for general illumination although it is eminently suited for out door lighting where the coloration effect is not objectionable.

Historical.

The efficiency of the mercury vapor in producing high candle power when used as the conductor of an electric current was first demonstrated by Professor Way of England in 1860. Professor Way used two mercury reservoirs each joined to a pole of the line. By opening a cock in the upper reservoir a fine stream of mercury flowed down and made connection. This fine stream of mercury acted as one electrode, the other was the mercury in the lower reservoir. For the second electrode he sometimes used carbons.[1] The current heated the fine stream and caused the formation of the mercury vapor

(1) Phil. Mag. Vol. 223. p 95.

in which the arc formed. Professor Way seems to have tried this in a vacuum as well as under atmospheric pressure but he gives us none of the details of the results nor does he draw any conclusion as to the best pressure to use. He seems to have thought the coloration produced by the light quite remarkable. Since the current sources at that time were only primary batteries it is not surprising that Way did not succeed in bringing his light up to popular expectations. Professor Way got patents for his lamp in England and America. A number of patents founded on the same principle as Way's lamp were gotten out after this time but none of them contributed anything essentially new to science.

Rapieff (1) in 1879 patented a lamp. He used a V shaped tube. By tilting the tube so as to bring the electrodes together and then by tilting it back again and separating the solumn he started the arc. He used a cooling chamber to condense the vapor but he did not try exhausting the air from the tube. He says, however, that it would be well to supply a vacuum.

In 1880 Rizet (2) got out a patent on a tube similar to the one patented by Rapieff. He proposed to alter the green blue of the light by using certain gases in the space between the electrodes.

The second period in the development of the arc began with Arons (3), a German Physicist of Berlin, who took up the study of the mercury arc in a vacuum. He says that while studying gaseous conduction he discovered an extraordinarily good arrangement for maintaining an arc between mercury electrodes for long periods and

(1) Eng. Patent 211 (1879)

(2) Am. Ins. of E. E. Vol. 22. p. 72.

(3) Annalin der Physik, Vol. IVIII p. 73.

without any of the troubles incident to such cases. He used an exhaustion of 1 or 2 mm. The electrodes were connected through a controlling resistance to a 100 volt circuit. To start the arc he raised the bulb A (see figure) containing mercury until the mercury over flowed into C and then lowered it starting the arc. He made a study of the conductivity of the vapor and reported that the voltage drop is principally dependent on the length of the tube and that the drop is about 6 volt per cm. for a current of 6 1/2 amperes. He found, too that there is a voltage loss of 8 volts at the anode and 6 volts at the cathode. The specific conductivity of the vapor he found to be 6x10-10 which is 8 times as great as the best conducting solution of sulphuric acid. He did some experimenting to determine the temperature. He noticed that the temperature in the arc rose to a remarkably high value. He was surprised to see that a small platinum wire when placed at right angles to the axis of the tube was melted down into a small sphere. He at first thought that the platnuum formed an amalgam with the mercury which in some way may have caused it to melt. To test this the small sphere (weight.148 gm.) was subjected to an intense blow pipe heat to drive off any mercury present, without the slightest loss in weight. Hense an amalgum was not formed.

In order to investigate the temperature of the arc he modified the regular tube (1) as indicated in figure 2 and suspended in the vertical branch a small thermometer with its bulb about 5 cm. below the side branch. Thus the bulb of the thermometer could be placed at various distances from the surface by simply raising or lowering the mercury in the vertical limb. He made temperature observations

for four different relative positions from the surface in the vertical limb, and then the polarity of the lamp could be reversed, hense he could measure to either the anode or cathode. The four temperature readings made were:

(A) The thermometer bulb submerged in the mercury.

(B) Just touching the mercury surface.

(C) When 5/10 mm above the surface.

(D) When about 5 cm above the surface.

By reversing the anode and cathode he got another set, all of which is set forth in the following table:

	In the Hg.	On the surface	5 mm above the surface	5 cm above the surface	In the Hg.	On the surface	5 mm above the surface	5 cm. above the surface
Current	Anode				Cathode			
	a	b	c	d	a	b	c	d
4 Amp.	100	285		400	400	270		375
5.5 Amp.	100	345	515	465	100		380	430

This vacuum was perhaps not over 1 or 2 mm although he does not say here just what he did use.

In carrying our the observation the thermometer was broken by plunging the hot thermometer into the mercury of the anode. He did not think it necessary to replace the broken apparatus. The fact that the platinum wire placed at the center of the tube was melted indicates that the energy of the mercuty vapor along the axis is very great and sufficient to melt a small platinum wire. The walls

of the tube were not heated very much, hence there must be a very large temperature fall from the axis to the wall. Concerning the temperature variations along the axis of the tube he found that the highest temperature obtained was in the center over the anode, from this it fell off gradually toward the cathode. The mercury just below the surfaces of either the cathode or anode had a very low temperature which was approximately that of the bath surrounding that of the apparatus.

The high temperature reached in the arc between electrodes of metals, or rather materials, whoes boiling points are low is not a new observation. Violle observed that an arc between a zinc electrode and a thin carbon rod which was made thiner and thiner and finally a thin thread, became white hot. He concluded from this that the temperature which the carbon filament assumes may be higher than the boiling point of zinc (930 degrees); that the thermometer gives a lower temperature lies in the thermal capacity of the extremely rare vapors.

Wargurg purposed a formula for the temperature of the gas in a geisler tube which does not apply to this case. He found that the temperature of the inner wall is given by the equation:

$$u_1 = .0378 \frac{Vi}{K'} \frac{\sigma}{R}$$

where R is the radius, σ the thickness of the glass wall, V the potential gradient i. e. in volts per cm, i the current in amperes k' and k are thermal constants founded on gram, cm sec and degrees centigrade.

$$u_0 = u_1 + .0189 \frac{Vi}{K}$$

from this formula Mr. Arons computed the temperature of the arc to be 4600 degrees centigrade.

The Arons lamp had to be run with a very high ballast resistance and this spoiled the high efficiency that the lamp has in itself, because so much of the energy was absorbed in the ballast. Arons did not use a condensing chamber. He could make his lamp (a later form) satisfactory only by absorbing in water the heat developed by the lamp. The electrode A and B (fig 2) were placed in running water The condensation then took place within the electrode part of the casing.

Weintraub[(1)] continued the scientific research of Arons. He performed a series of experiments with the arc which showed that in order to start the arc at moderate voltage the cathode must first be rendered active and from this he concludes that an ionization process must be started at the surface of the cathode in order to allow the passage of a current through metallic vapors; that the primary generation of ions takes place at the cathode and that the anode receives the arc.

Weintraub found that he could destinguish three kinds of mercury vapor in the arc stream; one ironized and conductive, a second non-conductive but light emitting and the third ordinary mercury vapor, non-conductive and non-luminous. When a condensing chamber is provided so that this non-luminous, non-conductive vapor is readily condensed the resistance of the lamp is greatly reduced for the ordinary mercuty vapor produced by superfluous

(1) Phil. Mag. Vol. 223 p. 95.

vaporization hinders the motion of the ionized particles. When a lamp without a condensing chamber was placed in running water he found that the voltage drop changed from 42 to 34 volts. This shows that the condensing chamber is of considerable importance.

Weintraub devised a method for starting long arcs with moderate voltage by using an auxiliary starting device. He used an auxiliary anode very near the cathode and so arranged that the mercury column joining these was separated and the arc started by an iron pin being drawn up out of the auxiliary anode by a solenoid. This form of lamp is shown in figure 3. He agreed with Arons that the resistance of the arc can be considered inversely proportional to the current for the voltage increases but very little with the current. He found the potential drop in tubes 3/4 in diameter to be 1.8 volt per inch; that the drop at the anode is 8 volts and 5 volts at the cathode.

Certain experiments were performed upon the arc as early as 1882 which showed that the arc can be made to serve in changing an alternating to a direct current. It was found that where one of the electrodes (the anode) is of carbon the alternating current passes in the form of an arc much more readily than where both electrodes are of metal. Weintraub showed that by making a cathode common to two circuits as shown in Fig. 4, one of the circuits supplying an alternating current, the alternating current could be rectified. The direct current is used to keep the cathode in a state of agitation, otherwise the arc would go out with every half wave. By this method only a half wave passes and always, of course, in the same direction. This application of the mercury arc has become of great commercial value.

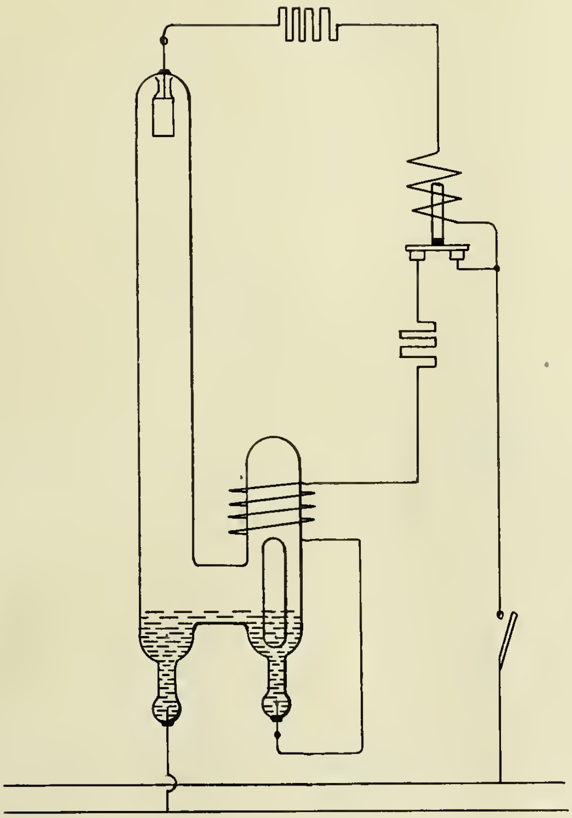


Fig. 3

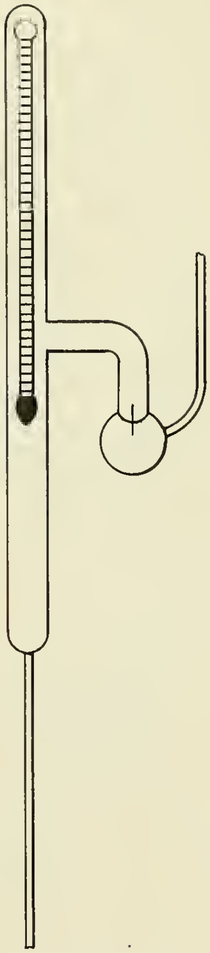


Fig. 2

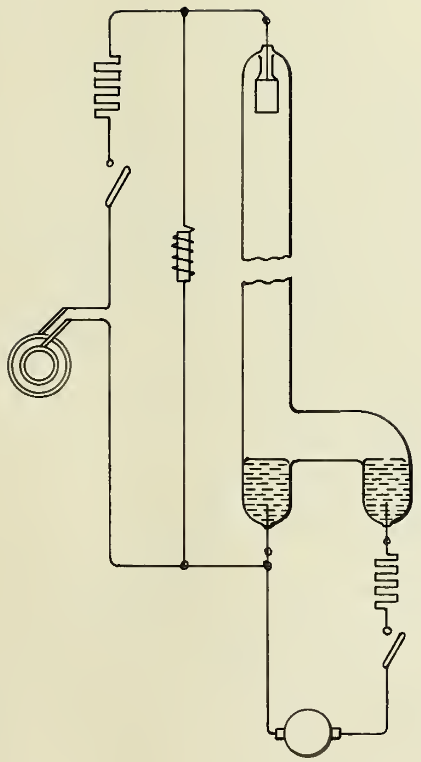


Fig. 4.

The third stage in the development of the lamp begins with the patents by Peter Cooper Hewitt in 1901. To Mr. Hewitt the credit is due for making the lamp a commercial success. He may almost be said to be to the mercury lamp what Edison was to the incandescent lamp.

Mr. Hewitt used other vapors besides that of mercury in his lamps but he found the mercury most efficient. Because of its molecular wright and low vaporizing point it is well adapted to the purpose of lighting. Then too, it readily serves under the influence of the current to transfer the heat generated in the lamp to convenient points for radiation. The Hewitt lamp was constructed with the object of utilizing all the resistance of the lamp in the conversion of the electric energy into light. Mr. Hewitt used as a condensing chamber an enlargement of the tube beyond one of the electrodes. He found that if the heat developed by the lamp be allowed to accumulate it greatly increased the resistance of the lamp and would finally cause the lamp to extinguish itself. The condensing chamber conveys the heat away.

Mr. Hewitt investigated the three kinds of resistance of the lamp; that of the electrodes and the vapor path. He found the anode resistance to be the same for starting as for normal operation. The resistance of the gas proper he thought to be partly due to vapor molecules filling the space. He found that the high resistance of starting was due to the high resistance of the negative electrode. To get a low cathode resistance the electrode must be disintegrating and as mercury disintegrates easily and replenishes

(1) Elec. World Vol. 37 p. 503.

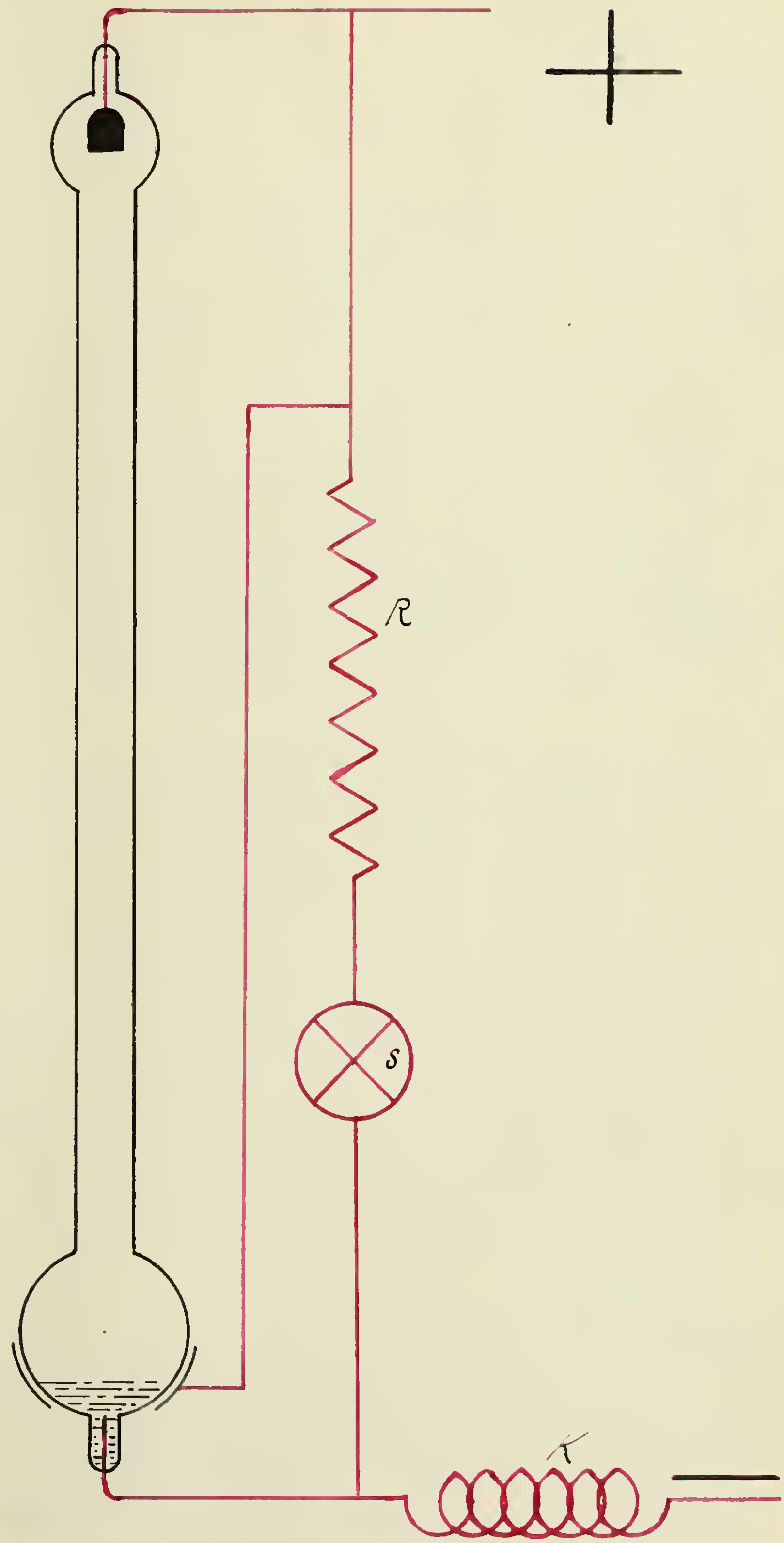


Fig. 5.

itself he used mercury for the cathode and mercury, iron, copper or similar material for the anode.

One of the patents gotten out by Mr. Hewitt was a device for producing an induction high voltage shock sufficient to overcome the starting resistance and start the operation of the lamp. In figure 5, S is a quick circuit breaker. The breaking of the current in this causes a momentary high potential impulse from the choke coil K, which is applied both to the starting band in the neighborhood of the negative electrode and to the main positive electrode. The former serves to break down the starting resistance of the negative electrode, and the latter supplies the starting voltage for the vapor path.

Mr. Hewitt by a series of experiments described in the Electrical World 1901 p. 679 showed that the voltage loss in the lamp is more or less proportional to variation of vapor pressure and to the temperature of the electrode and that it also depends upon the chemical composition of the vapor. He found that the voltage loss is directly proportional to the length of the vapor and is inversely proportional to its diameter; that it is nearly independent of the current strength but varies slightly in the direction opposite to the current.

The point at which the current enters the negative electrode is constantly shifting about over the surface of the mercury producing a flickering of the light. Hewitt prevented this flickering by placing a porcelain cap having a small aperature in its center

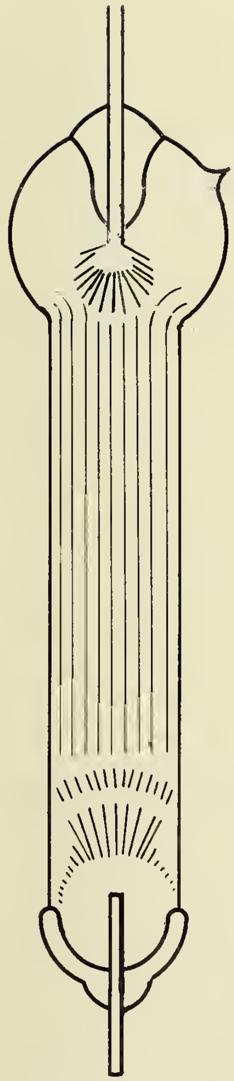
(1) E. E. World 1901 p. 679.

over the electrode. The current was thus kept from wandering about. He accomplished the same r esult by allowing a platinum wire to extend up through the surface of the mercury.

Some interesting work has been done in the laboratory of Mr. Hewitt by Mr. A. P. Wills.(1) Mr. Wills describes the general phenomena of the Hewitt lamp. Diagram 6 shows a common form of the Hewitt lamp, the anode at (aP is of iron. When the lamp is operating normally the region from (a) to a point at about the opening of the condensing chamber is practically non-luminous and is called the anode dark space. The luminous column following this extends to (d) where there is a narrow luminois section, and following this a dark space extending to the negative electrode but penetrated by a cronical flame which enters the cathode at the flickering point. If the tube is made to carry a very high current the luminous column extends all the way down to the anode. This is called arcing. The current appears to leave the electrode over a considerable surface. At times a blue velvety glow will appear over the whole surface of the electrode a condition which is accompanied by a large increase in the potential drop over the anode and also in the temperature.

The length of the negative dark space at the cathode depends very much upon the current and the diameter of the tube and the vapor density. The temperature of the dark space except near its junction with the luminous column, and possible in the negative flame, is low in comparison with that in the luminous column.

(1) Phys. Rev. Vol. 19 p. 66.



The luminois column appears brightest at the axis of the tube and falls off gradually toward the walls.

To determine the temperature in the discharge and its variation along the tube Mr. wills used a tube such as shown in figure 6 with thermo-couples at a , b, c, d along the tube. The tube was 1.9 cm in diameter so the ccuples extended into the tube less than one cm. His results are shown in the following table:

Room Temperature 20

	Temperature in degrees centigrade			
Current in Amperes at	a	b	c	d
1.25	123	83	105	134
1.75	143	88	143	160
2.25	172	125	175	200
2.75	200	123	205	241
3.25	243	167	242	297

a was at about 1 cm from the anode and d about a cm from the cathode.

Some interesting theory as to the phenomena connected with action of the mercury arc is given by Thomas (1) and is summed up as follows: a current of electricity is only a stream of electrons moving in a direction opposite to the conventional current direction. In the mercury lamp there is a continuous stream of electrons passing from the negative to the positive electrode and returning through the external circuit. These electrons are set in motion by the

(1) Amer. Ins. Vol. 25 p. 608.

electromotive force of the circuit which causes an increase of potential or deficiency of electrons at the anode and the opposite condition at the cathode. The voltage loss in the vapor itself is probably due to the r esistance offered the free motion of the electrons by molecules or atoms of the gas. The resistance then increases with the pressure of the gas. The molecules or atoms of gas being struck by the electrons are caused to give off both light and heat, the light having the spectrum of the gas atom. As the negative electrode is the source of the electrons which enter the vapor the surface tension of the mercury may prevent their breaking through until the flow is started. After that either because of the local heating of the negative electrode or because of the rapid evaporation at the negative spot there is no chance for a new surface to be formed. This explains the negative electrode resistance. There is then within the tube two streams of material electrons passing from the negative electrode to the positive and the atoms of mercury vapor passing from the hot mercury surface to the cooler parts of the tube. Both of these streams of particles have the power of carrying with them atoms and molecules of any gas which may be found in the vacuum space. There will consequently be a piling up of the gas at the positive electrode where it will be absorbed by the mercury. Consequently a lamp may improve with operation.

Perhaps the latest development of the arc is found in a process for the distillation of mercury recently patented by Dr. Knipp. The tube which he used is shown in figure 8. The tube is provided with a tube extension downward from each electrode. The length of

these leg tubes is about 76 cm. Through them the mercury is drawn up into the electrodes when the tube is exhausted. Midway between the electrode and on the upper side is the large condensing chamber. The condensed mercury runs off from this chamber and is collected from the leg of the delivery tube. With a large still and high current the distillation can be carried farward with considerable rapidity. The process gives promise of being especially valuable where high degrees of purity are desired.

Summation of opinions and theories.

It will be seen from the foregoing review of the work on the mercury arc that the temperature has a very important bearing on the operation of the light. Contrary to the action of an incandescent body the light efficiency of a vapor does not depend upon the heat developed but is greatest at low temperatures. The temperature directly effects the pressure and an increased pressure causes an increased resistance which in turn causes a rise in t emperature. The increased resistance however tends to cut down the current and reestablish normal conditions.

The result obtained by Arons in his work on the temperature seems to be unquestionably in error. If the vacuum used were very poor and the current high the temperature was undoubtedly very high, but it is not clear how platinum which melts at 1775 c could be melted in a glass chamber for glass softens at about 700 c. Of course it is much harder to see how a temperature of 4500 c could have been reached with a 6.5 ampere current. While the temperature is undboutedly much higher at the center of the tube than

at the sides it does not seem probable that there would be so great a falling off as would be necessary in the cases mentioned even though the tube was very large.

Mr. C. D. Child (1) finds fault with the determination of Mr. Wills which places the temperature at from 200 to 300 degrees for ordinary currents and assumes that the temperature is a thousand degrees or so centigrade.

Mr. Steinmetz (2) made a theoritical determination of the temperature and found it to be between 200 and 250 c. This value which is not far from the experimental determination of Mr. Wills is about what we should expect in a gaseous discharge such as that of the mercury arc. E. Weidmann (3) proved that the average temperature of air at a pressure of 3 mm in a tube conveying a luminous discharge is less than 100 c. He also showed that the distribution of temperature along the tube depends materially upon the pressure.

Wood used a bolometer floating on a column of mercury, which could be placed at any position in the tube. In no case did he find the temperature to be over 100 c.

If in an ordinary discharge through gases the temperature is very low we should not expect to find very high temperature in the similar phenomenon of the mercury arc. I do not deny that the temperature for individual molecules may in some cases be very high but I take it that the average temperature is what is meant in all of the foregoing results.

(1) Phys. Rev. Vol. 19 p. 134.

(2) Thomson, Conductivity of Electricity through gas p. 469.

(3) Amer. Ins. of Elec. Engineers Vol. 25. p. 629.

Experimental Work.

The justification for this investigation rests in the uncertainty as to the acutual temperature of the arc. The determination of Arons need be no longer seriously considered and those of Mr. Wills are only for low current, are only for four joints in the tube and, since the junctions were placed in the gas there was a possibility of contamination. Then too since the distance from the junction to the outside of the tube was only one cm. and since along the path of the wires leading from the junction there must have been a considerable falling off in the temperature it seems probable that there was a considerable heat loss from conduction along the wire. At any rate this is a very probable source of error.

From a commercial standpoint a careful determination of the termperature and the condition effecting it should have an important bearing upon the improvement of the light efficiency.

Apparatus.

The tube used was the same as shown in figure 8 and is the one used by Dr. Knipp in his work on the distillation of mercury. Because of the openings into it at the electrodes it is well fitted for this kind of an investigation. The tube was exhausted by a Gergk power pump driven by a 1/4 horse power induction motor. The pump is rated to reach an exhaustion of 1/5000 of a mm. If the pump were in perfect condition it might attain this vacuum but measurements taken with the pump in series with the arc and a guage showed that .04 mm wqs about the best exhaustion reached and that this fell off to as low as .1 of a mm depending perhaps

THIS IS THE TUBE USED IN MAKING THE TEMPERATURE MEASUREMENTS.

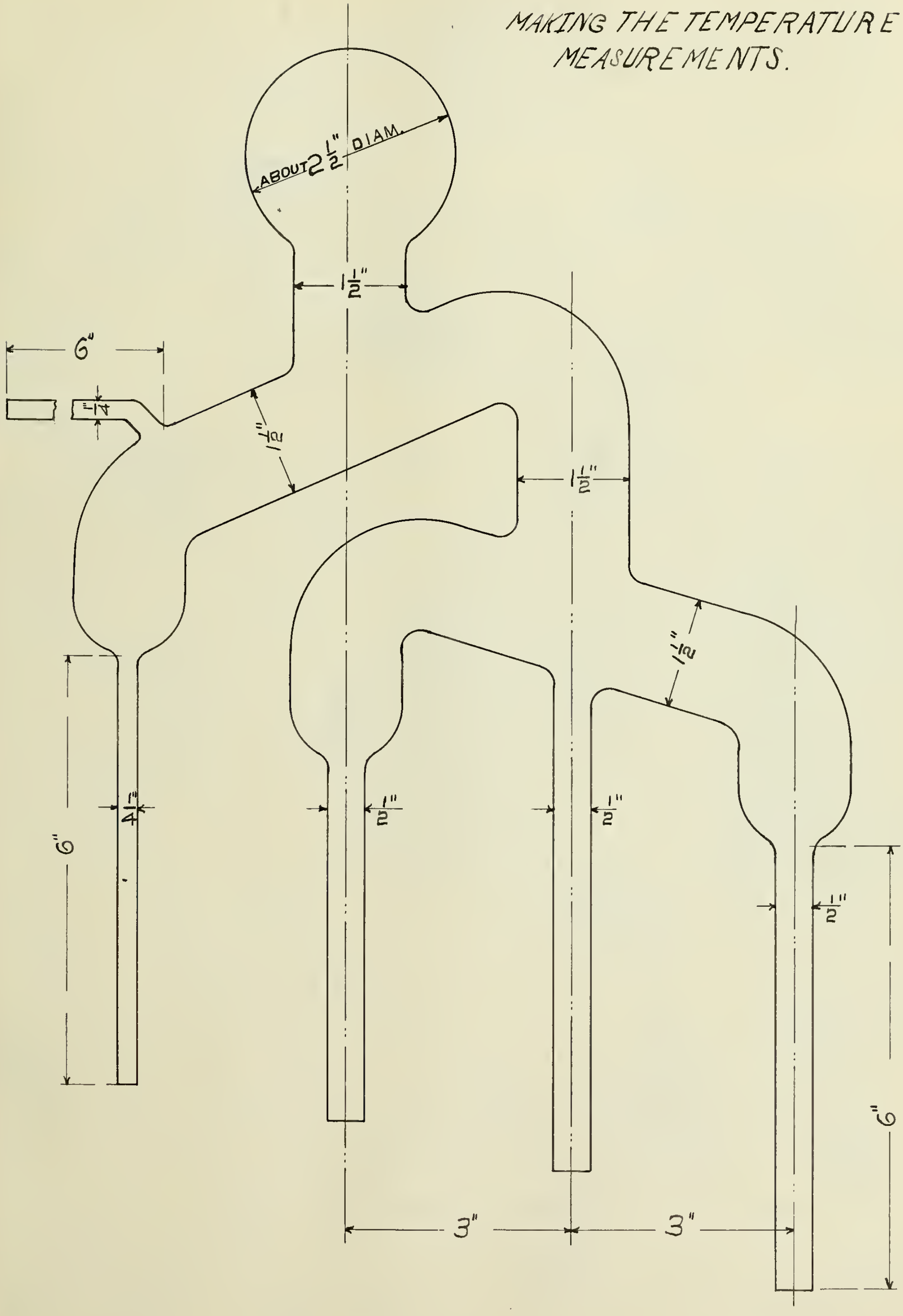


FIG. 8.

on the proper use of oil in the pump.

A drying tube containing phosphorous pentoxide was in the pump circuit, and all joints were covered with mercury seals. The form of the seals is shown in figure 7.

An auxiliary positive electrode was formed at the midway opening. The legs of the three electrodes dipped into test tubes of mercury, by adding mercury at the middle tube the mercury at the top was caused to overflow into the negative electrode and so start the arc.

The junctions for the temperature measurements were made by fusing together in a blow flame copper and platinum wires. The platinum wire for junctions 1,2 was of size .18 mm diameter and for junction 3 .24 mm diameter; the copper wire was .44 mm diameter. These junctions were placed in glass casings of 1 1/2 mm internal diameter. The casings each had a bulb blown at the upper end and an upward bend at 83 mm below the top of the tube, as shown in figure 10. I found it most convenient to make the tube in two pieces and weld the pieces together. In order to get the junctions inside the casing a small opening was left at the tip of tube. A wire with a hook on the end was run through the opening and hooked to a similar arrangement pushed in from the other end. A thread was attached to the wires at the lower end and the junction fastened to the thread. The junction was then pulled up into its proper place in the bulb. Great care was taken that the wires should not touch at points where the insulation had been burned away. With one of the tubes which had been previously prepared by Dr. Knipp asbestos was put between the wires. The casings containing the

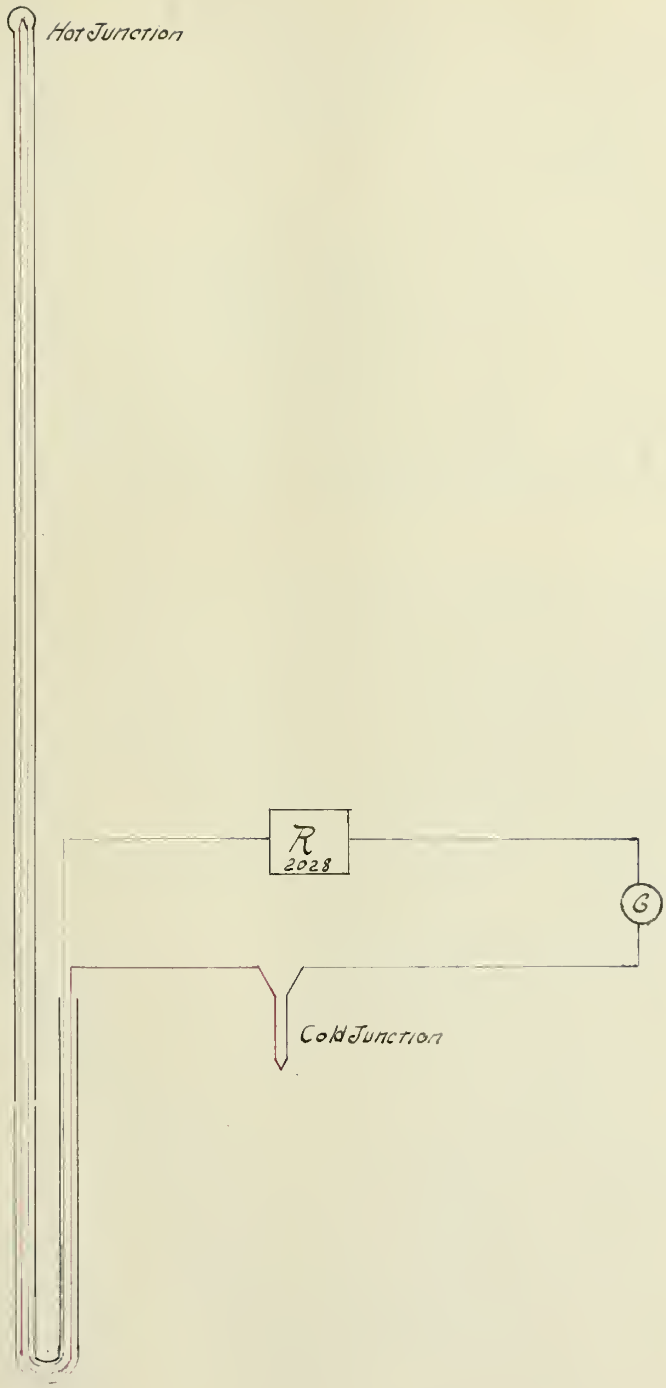


Fig. 10

junctions were then inserted in the legs of the tube so the junctions could be placed at any point in a vertical line in the region of the part of the column to be investigated. The bend in the tubes brought the wires up through the mercury. The height of each junction was adjusted by means of a rubber collar which could be pushed up and down along the leg of the tube. The lower upward turned end of the casing pressed against this being buoyed up by the mercury, so the height was easily regulated. The cold junctions were placed in ice.

Any of the junction circuits could be made to include the galvanometer. This instrument was the type H Leeds and Northrup ballistic galvanometer having a resistance of 242 ohms, a sensitiveness of 4.52x10-9. The scale, which was a meter in length and graduated in millimeters, was placed at a distance of two meters from the galvanometer. In order that there should be no need of a correction for the angle of deflection the wooden back which held the scale was shaped into an arc of a circle of two meters radius. A telescope was used for taking the readings. In order that the readings of the three junctions might be taken in quick succession it was necessary that the coil return quickly to the zero position. The galvanometer which we had at first intended to use was much more sensitive than the one employed but its period was very long. An additional resistance of 2028 then was placed in the galvanometer circuit. This made the instrument of proper sensitiveness to allow the extreme reading to be taken at the end of the scale. It was essential that the resistance in the galvanometer circuit be high

enough to prevent errors on account of change of resistance at the couples due to variation of temperature. As the variation was probably not over half an ohm the error introduced would not be over 1 in 4000.

To change the galvanometer readings to temperature a calibration curve was made for each couple and the temperatures were then read from the curve. The junctions were calibrated by means of a standard mercurial thermometer and an oil bath. The bath was especially constructed for the calibrating of thermometers and thermo junctions over a range through which the oil could be heated. It consisted of a four inch gas pipe about 15 inches high capped at the lower end. This vessel was covered with asbestos and heated by a current of about six amperes sent through two coils of wire in parallel around a perforated metallic cylinder placed in the bath, and was kept in motion by a fan stirrer driven by a 1/16 h.p. induction motor. The oil used was high temperature gas engine lubricating oil. The current could be lowered to any desired value by regulating the resistance in the circuit. The thermometer used was a fahrenheit instrument manufactured by Green and Company. It had been compared with standard thermometers at the U. S. Bureau of Standards. Corections were made of + 1 degree at 212 degrees + 1 degree at 300 degrees, 0 at 390 degrees, - 2 degrees at 480 degrees, -5 degrees at 580 degrees and -11 degrees at 680 degrees. By drawing a curve with correction as ordinates and thermometer readings as abscissae corrections were made for any desired point of the scale.

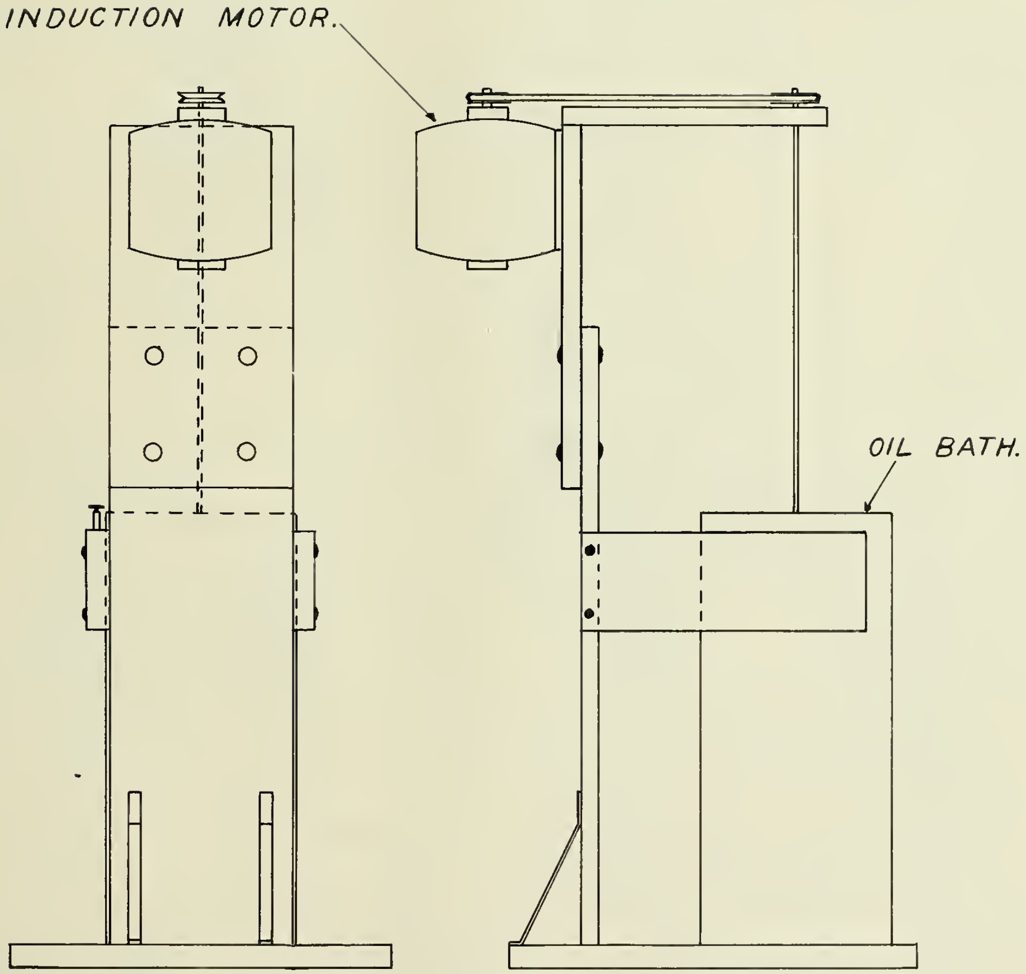


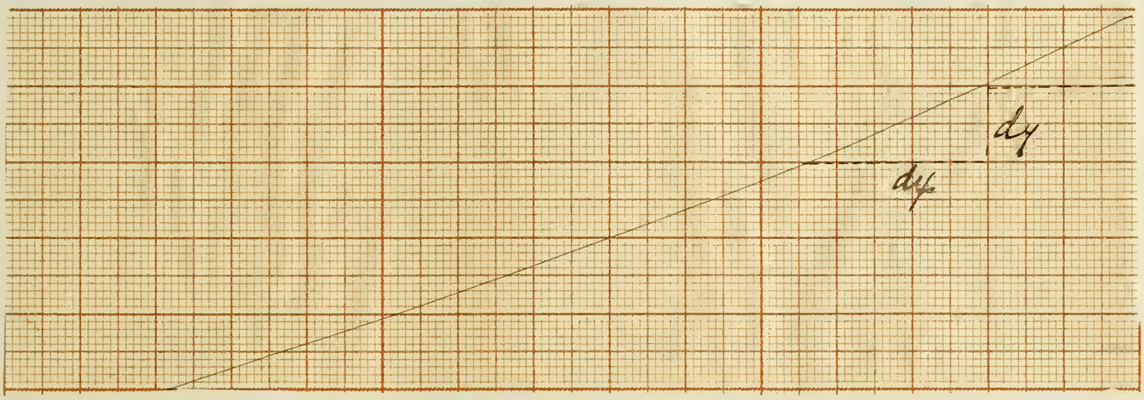
Fig. 11

The thermo junctions were bound to the bulb of the thermometer care being taken to insulate the wires and to keep them from becoming entangled. The thermometer and junctions were then placed in the bath and the temperature raised to 212 degrees. By lowering the current a value of current was obtained where the heat gained in the bath was just equal to the heat radiated. After allowing the temperature to remain stationary for a couple of minutes the deflections were read on the galvanometer. The heat was then increased and the temperature read again at about 30 degrees higher and so on up the scale the highest reading being at 650 degrees f.

To get a still higher point the melting point of zinc was used. By means of an electric furnace, jurnished by Clement of the heat laboratory, this point was obtained. A block of zinc was put in its proper place in the furnace. The junction to be calibrated was put inside a porcelain tube whichwas so placed that it rested on the top of the block of zinc. A current of 15 to 20 amperes was sent through the coils of the furnace metling the zinc and allowing the porcelain tube with the junction to be immersed in the melted zinc. The heat was applied for a moment longer and then shut off. As the zinc cooled off readings were taken till it had passed through the melting point. This point was taken to be where the readings remained constant for several minutes for there is no change in the temperature while the change of state is taking place. The melting point of zinc is 419 degrees.

To extend the curve farther and also to find what points were off the curve the equation of the curve was computed. It was found to be almost a perfect parabola. The curve had been plotted by

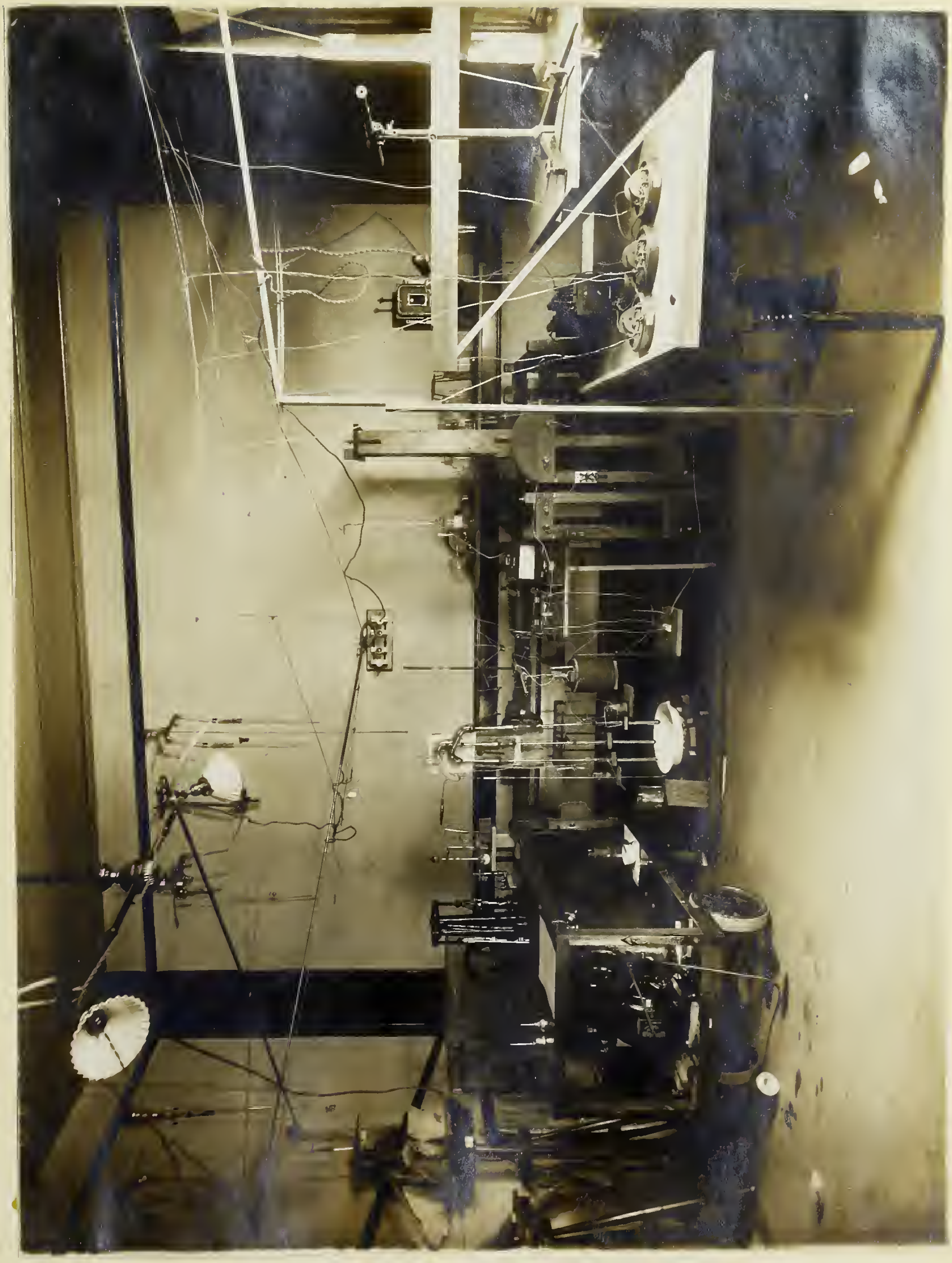
taking the deflection of the galvanometer as ordinates and the temperature corresponding as abscissae. The value of dy/dx was then found for every 20 degrees along the curve. The difference



between successive values of the first differential should be constant. This constant is the second differential. By examining the second differential it was easily determined as to about what the constant should be. Where the second differential varies much from what it should be the points in that vicinity were taken to be in error. $dy/dx = c + c$ in any case, c, being the preceding first differential and c_2 the constant. The curve could be extended as far as desired by use of this formula. Figure 11 shows the calibration apparatus and the set up.

The photograph on page shows the entire apparatus as set up in the laboratory and figure 12 shows the arrangement in diagramatic form.

Small paper scales were posted on the legs of the tube under the rubber collars in such a way that the junctions could be adjusted to the distance, from the surface of the mercury, desired.



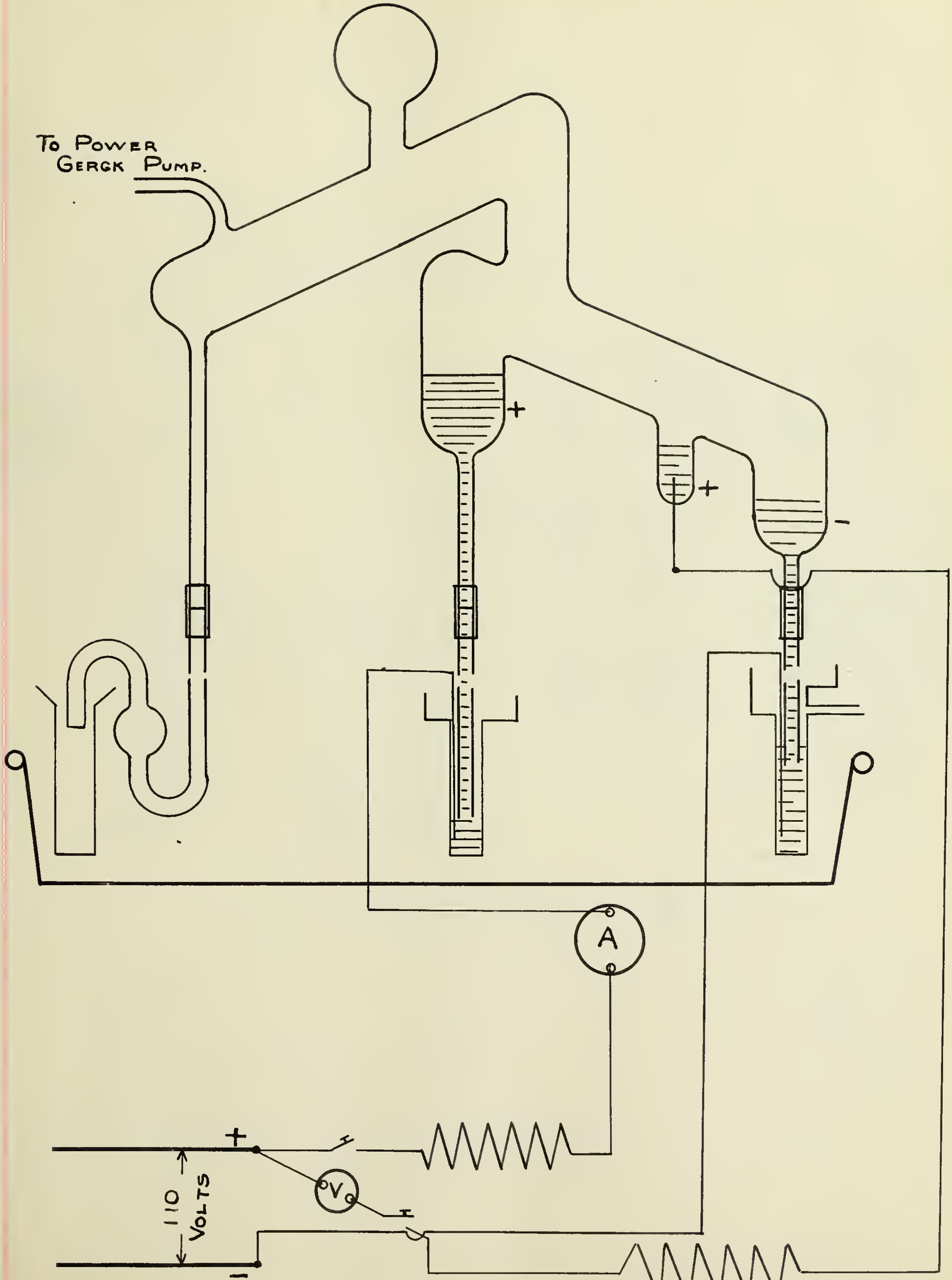


Fig 12

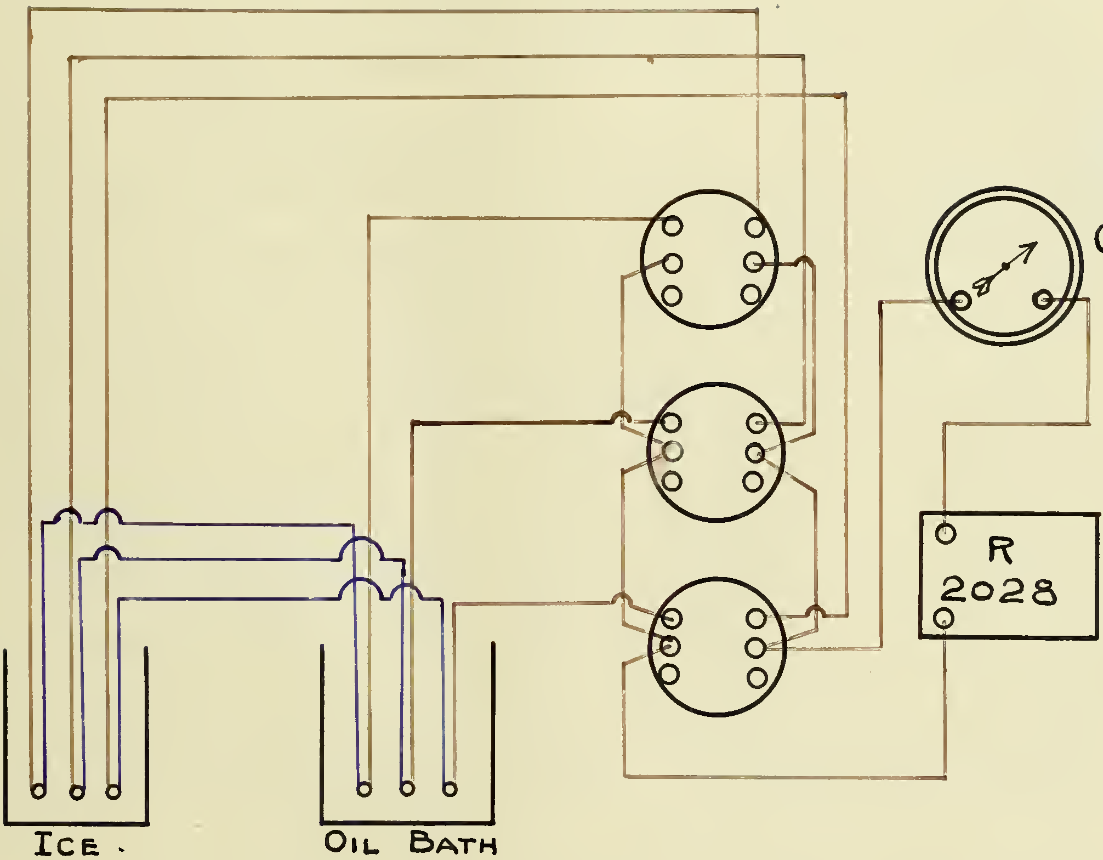


Diagram showing arrangement of apparatus in calibration of Junctions.

The height of the mercury at the electrode was kept constant by a siphon connection with a larger vessel as shown in figure 13. A voltmeter reading up to 150 volts was used to read the impressed e. m. f. and also the drop between the terminals of the lamp. An ammeter reading up to 15 amperes registered the current in the lamp. The current was varied as desired by adjusting the tin resistance in the lamp circuit.

I found some difficulty in getting the tube so that it would not leak. If the exhaustion was poor it was quickly shown by the red color of the light. If the lamp was run when this red was present the tube soon became coated over with oxidized mercury. It is essential in the operation of the arc that the vacuum be high. If the vacuum is only fairly good the tube will cloud up at first but after the light has operated for a few minutes the deposits will disappear. This may be due to the absorption of gas at the positive electrode and a consequent increase in the vacuum or the heating may cause some of the residual gas to be drawn over by the pump.

At first there was a leak through the seals on the legs of the tube, the mercury in the seals being sucked into the tube. I put on new rubber connections and coated these with vaseline. The result would have been satisfactory had not some of the vaseline gotten into the mercury. This first showed itself at the surface of the cathode where a greenish deposit formed and spread over the inside of the tube. The surface of the electrode seemed gummy and the electrode spot remained almost stationary near one side of the tube. I took the tube down and cleaned it thoroughly with a mixture

of H C L and H N O_3 and washed it in distilled water and thoroughly dried it. I put clean rubber connections on the lamp and set it up and exhausted it again. Small bubbles of air kept coming to the surface for some time after the pump had been started. This was caused by imprisoned air particles escaping from the neighborhood of the joints and on reaching the surface expanding under the greatly reduced pressure. After running the pump for a couple of hours the lamp started up clear and white. The light is not good for the eyes. It gave me a severe headache at first. Dr. Knipp had the same experience and Mr. McCrea, who helped me, also complained of a headache. Green shades over the eyes remedied this difficulty.

Eighteen sets of data were taken. The junctions were placed below the surface and the current started at 3 1/2 amperes. Every six minutes it was raised about .6 of an ampere and just before increasing the current each time the galvanometer readings were taken. The current was thus increased up to 8 or 10 amperes and then was decreased at about the same rate to the minimum of 3.5 amperes. The junctions were then raised to the surface and another cycle of readings taken. The distance above the surface was increased a half cm. for each new set of data till the junction had been raised to the maximum height.

A second series of sets of readings was then taken by keeping the current constant and varying the distance of the junction above the surface. This was done for all whole number values of current from 4 to 8 amperes. The middle junction could be raised 11 cm. and those at the electrodes 4 1/2 cm above the mercury surface.

When this had been finished the junction at the anode was put in the place of No. 2 which was broken just as the last readings were being taken.

An examination of the data shows that the temperature rises in almost the same ratio that the current is increased for all points of the tube but that this increase is slightly more rapid for high currents than for low. The temperature increases with the distance above the surface till it reaches a maximum at about 3 1/2 or 4 cm above the surface. This shows that the dark spaces above the surfaces of the electrodes are cooler than the luminous column and further observation shows that the region just over the cathode is the cooler of the two dark spaces. At about 4 cm above the surface the junctions 1 and 3 leave the axis of the tube and as they approach the wall there is a considerable falling off in the temperature caused by radiation. This falling off by radiation is also shown by the midway junctions, which, as it is pushed in toward the axis of the tube shows a rapid increase in temperature.

Comparing the temperatures at the regions adjacent to the anode and kathode I find that below the surfaces for a current of 3.5 amperes up the temperature is always the highest at the kathode. At the surfaces the temperature is highest at the anode up to a current of 6.5 amperes. At 1/2 cm above the surfaces it is highest up to 5 amperes, at 1 cm above the surfaces it is highest to about 3 3/4 amperes at 1 1/2 cm above it is highest up to about 4 amperes but at 2 cm above the surfaces the current is considerably the highest at the cathode. This shows that the cathode dark space must shorten and that the luminous column must approach the surface

of the electrode. There is also some indication of a secondary dark space above the surface of the cathode.

An examination of all the data shows that the hottest part of the discharge for the parts investigated is just in the center of the opening to the condensing chamber. This may be due to a less amount of radiation at this point for the temperature falls off very gradually into the chamber and so there can be but little heat radiated into it.

The highest temperature reached was 469° at 4 cm above the cathode for a current of 8.45 amperes. Adjusting the current to 4 amperes the lamp gives off about as much light as the ordinary commercial lamp; the temperature at 1/2 cm above the surfaces is 113 degrees at the cathode, 132.2 degrees at the anode and 970 at midway; at 2 cm above the surfaces it is 186 at the cathode, 165.2 at the anode and 136 at midway; at 4 cm above, which is the point where the highest temperature is reached in this case, the cathode temperature is 224 degrees, the anode 183 degrees, and midway 216.5 degrees.

Examining the curves where readings are recorded for temperature up to a maximum value of current and then down, the distance above the surface being constant, it is observed that there is a lag in the falling off of the temperature; that is, the temperature does not fall off quite so rapidly as it goes up. Of course this may be an indication that sufficient time was not allowed to elapse between readings to allow the junctions to take on the temperature of the gas. It will be observed that for curve No. 5 this lag is

considerable. Here the time interval was a minute shorter than in most of the other cases. If we take the voltage loss at the electrodes as constant at 13 volts (value determined by Mr. Steinmetz and Mr. Childs) and from this find the drop through the tube and plot these values as abscissae and the corresponding currents as ordinates we find a lag in the voltage drop corresponding to the temperature lag. There is then some hysteresis action taking place as the current is decreased.

When operating a small lamp on a very low vacuum 1 or 2 cm, and a moderate current the tube got hot enough to soften the glass and draw an opening therein. I was led to conclude that the pressure has a great deal to do with the temperature. I was also led to this conclusion when I found it difficult to get a good vacuum in the tube, in which case the light was slightly red in color and the tube got very hot. In order to determine fully the affect of pressure on the temperature of the arc a Mc Leod guage should be used in the system to record the pressure.

Errors.

Besides the common errors due to manipulation care must be taken in using thermo junctions to guard against certain possibilities of error characteristic of thermo junctions.

These may be summed up as (1) Errors due to contamination of the junctions when used in a gas or liquid. (2) Errors due to variation of temperature at the cold junction. (3) Errors due to variation of resistance at the hot junction. (4) Errors due to heat

being conducted away by the wires of the junction. (5) Error due to not giving the junction sufficient time to take on the temperature. As to the first of these sources of error the glass casing fully protected the junction from any possibility of contamination from the mercury vapor. Regarding the second, since the cold junctions were always kept in melting ice there could hardly have been an error from variation of their temperature. Special care was taken to include enough resistance in the galvanometer circuit to make the small change in resistance at the hot junction negligible. To allow the junction sufficient time to take on the temperature of the gas, which is not done rapidly, six minutes was given between readings. At the end of the interval the temperature showed no tendency to increase. The error due to heat conducted away by the junction is probably the most likely source of error here. But since the junction extended up through hot mercury inside of glass casing there could not have been very much conduction of heat away from the junctions for the glass would become well heated to a considerable distance down and in turn heat the wire so that there would be little difference in temperature between the junction and the parts just below. Since the wires used were very small there is much less likelihood of error from the source than there would be with larger wires.

The objection may be raised that the results obtained show only an average temperature and that individual molecules may be vastly hotter than the investigation shows. This is no doubt true yet in any temperature determination do we expect to get any thing more than an average temperature?

Summary.

The conclusions reached from this investigation are:

(1) That the rise in temperature for all points in the tube is very nearly directly proportional to the current.

(2) That the temperature increases along the axis of the tube from the surface of the electrodes for about 3 1/2 cm at the anode and for about 4 cm at the cathode.

(3) That the temperature increases rapidly along a line at right angles to the axis of the tube.

(4) That the anode dark space is hotter than the cathode dark space. As the temperature is increased these dark spaces shorten and finally the luminous column extends almost to both electrodes.

(5) That the hottest of the points investigated in the special tube that was used is about 3 1/2 or 4 cm above the midway point of the tube and at the opening of the condensing chamber.

(6) That the temperature is strongly affected by the pressure of foreign gases within the tube.

(7) That the lamp is most efficient at low currents.

Data 1.

Since much more of the condensed mercury falls back to the - elec. than to the + the - is cooled more than the + but after a time the cooling is not enough to keep the of the - from rising above that of the + .

Junctions were below the surface while these readings were taken.

Zero at 500.

Data taken at 6 minute intervals.

Room t.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	59.2	37.1	54.2	94	70	92.2	3.65	21.2
23.2	65	46	62	100.5	81	101.5	4.2	22
23.8	69	50.2	67.2	105	86	108	4.8	22.3
23.4	73.5	54.6	73.5	110.5	90.6	116	5.92	22.8
23.5	77	57.6	78	114.8	95	121.5	5.38	22.9
23.7	78	62	84	116	100	129	6.8	23.5
24	84	67	90	122.8	106	136	7.21	25
24.7	89	72	97	128.5	112	144	7.9	26.9
24.7	87	70.5	93	126	110.5	138	7.22	26
24.7	83	67	87	121.7	106	132.2	6.6	24.3
24.4	78	62	79.8	116	100	124	5.99	23.1
24	75.3	58	75	113	94.7	118	5.44	22.3
24	74	55	71.4	111	92	113.5	4.9	22.4
24	70	51	66	106.8	87	107	4.3	22.2
23.6	64	45	59	99	80	98	3.5	21.6
23.6	65	45.2	59	100.5	80.2	98	3.49	21.6

It was rather difficult to be sure that the junctions were just at the surface.

Junctions were just at the surface.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
21.8	67	35	52	103	67	90	3.5	21.8
	77	47	63	111	83.5	103	4.1	22.5
22.5	81.1	53	68	119.2	90	109	4.5	22.6
	83	58	74	122	96	117	5.5	22.9
23.2	88	63.5	80	127	102	124	5.8	22.9
23.8	90	68.2	85.5	129.4	108	130.5	6.5	23.2
24	92	72	90.2	132	112.8	138.5	7	24
24.8	95.5	76	95	135.5	117	141.5	7.5	25
25	97.5	80	101	138	122	148	8	26
24.8	105	86	109	146	129.4	151.5	8.5	27.5
26	97	82	101	137	124.5	148	7.5	26
25	88	75	88	127	116	133.5	6	23.4
24.6	83	65	77	122	104	120	4.5	22.8
23.4	78	53	64	116	90	104.2	3.5	22

Data 3.

Started the arc without first starting the pump and found everything all right. Not the least red was visible on starting the arc. Yesterday it seemed difficult to maintain the vacuum and I feared that there might be a leak in the upper end of casing NO.2. There is considerable tendency to variation of the current at high currents.

Distance of junctions above surface 1/2 cm.

Zero at 500

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	82	58	70	120.5	95.5	112	3.58	23.8
23.5	84	63	76	122.8	101.5	119	4.08	22.6
23.3	88	68	79.5	127.2	107	123.5	4.63	23
23.5	94	76.5	91.2	134	118	137	5.2	23.5
24	97	83	100	137.3	125.5	146.8	5.62	24
24.2	103.5	89	111	144.5	133	159	6.3	25
25	111.8	98	127.5	154	143	176	7	26.8
25	124	108.2	153	166.5	155	201	7.6	28.3
24.5	143.2	119	184.5	186	166	231.5	8.2	27.5
26	131.8	114	167	175	161	215	7.6	26.7
27	130	112	151	172.9	158.5	199	7	26.7
25.7	112	95	121	145	140	168	6.4	24.6
25	99	85	102.5	140	128.5	150	5.8	23.2
24.8	94	77.5	88	134	119	133.5	5.1	23.2
25	88.5	70	83	128	110	127	4.5	22.8
24.2	85	64	70	124	106.5	112	4	22.4
23.5	80	59	64	118	97		3.5	22

It should be noted here that the positive electrode is the hottest for the low current but that the negative rises most rapidly with the current.

At high temperature the loss from the + side is much greater than from the negative. This is due to the form of the tube. Enough condensed Hg. falls back to the neg. to keep it replenished.

Distance of junctions from surface 1 cm.

Zero at 500

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#2		
22.2	79	65	75	117	104	118	3.5	22.2
22.3	86	72	83	125	112	127.5	4	22.3
22.5	99	85	107	139.8	128	154.5	4.7	23.2
23	103.8	95.3	131	145	140.3	179	5.26	23.7
23	114	105.2	149.2	156	151.5	197	5.67	24.7
23.3	122	120	174	165	167.2	221	6.58	25.8
23.1	129	133.4	201.2	172	181	246.2	6.8	27.3
23.6	156	161	258.4	199	208	295	7.38	29.9
23.4	230	178	325	265	224	346.8	8	32
23.5	276	195	382	302	240	389	8.4	34
23.2	285	184	361	309	230	374	7.9	33.2
23.5	203	158	289.2	242	205	319.5	7.5	30.1
23.3	164	138	232	206	186	273	6.98	28
23.3	137	127	193	180	175.5	239	6.45	26.5

Room T.	Galvanometer Deflections in mm. #1	#2	#3	Temperature from curve #1	#2	#3	Amp.	Volts.
23	112	111	166.5	154	157.5	214	5.84	25
23	106	98	141	147	143	189	5.22	23.8
23.3	98	85	113	138	128	161	4.62	23.2
23	96	77	100	136	118	147	4.1	22.8
23	91	68	82	130	107	126	3.52	22.1

Suffered from a severe headache again last night. The green shades which we used yesterday did not seem to prevent the effect upon the eyes. Found the arc in good condition this morning. Put scale on the legs of the tube to adjust junction to proper height above the surface.

Distance of junctions from surface, 1 cm.

Zero at 500.

Data taken at 5 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
22.9	78.8	61	69	118	98	110	3.51	21.2
23.1	83.5	69	77.5	122	109	121	3.98	21.4
23.4	88	76.6	87	127	117	132.5	4.48	22
23.8	94.8	84.8	92.5	135	128	139	4.95	22.2
24	97.5	92	105	138	136	152.5	5.5	22
24.2	99.6	99	113	140.2	144	161	5.95	22
24.7	109	110	125.2	151	157	174	6.52	22.5
25	122	123	139	165	170.5	187.5	7.32	24
25.6	133	139	157	175.5	186.5	205	7.6	25
25.9	150.4	148.5	171	193.5	196	218	7.8	26.2
25.9	167	165	183	209	212	229	8.35	28
26.2	211	185	203	249	231	248	8.75	29.8
26.8	243.5	204	229	276	248	270	9.08	31.4
27	287	217	253	318	259	290.5	9.2	32.6
25.8	281.5	209.8	272	316.5	252.3	306	8.81	32

Room T.	Galvanometer Deflections in mm. #1	#2	#3	Temperature from curve #1	#2	#3	Amp.	Volts.
24.9	251.5	196.2	267	282.5	241.	302	8.38	31.1
25.3	188	175	203	227	230.5	247	8.00	28.7
24.7	168.5	156	194	210.5	204	240	7.45	27.2
24.7	147	141	176	190	189	223	6.93	25.5
25.7	125	127	147	168	174.5	195	6.4	24.2
25.9	111	112	134	153	158.5	182.5	5.9	22.8
25.9	106	105.5	122	141	146	170	5.67	22.2
25.8	96.3	97.5	113	136.5	142.5	161	5.22	22.1
25.9	92.5	91	98	132.5	135	144.5	4.63	22.3
25.6	88.8	80.	89.5	127	122	135	4.06	22
25.6	82.4	72.5	75.5	121	118	118.5	3.54	21.5
25	82.2	71	71	120.8	116	113	3.50	21.5
25							3.35	21.2

Data 6.

Distance of junction from surface, 1 1/2 cm.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
	113	77	98	155	118	144.5	3.5	22.2
	115.5	86	111	158	129	159	4.1	22.7
22.8	125.5	98	134	169	143	182	4.7	23.4
23.5	136	112.5	154.5	179	159	202.5	5.3	23.7
23.8	154.6	125	172	196	162.5	219	5.9	23.8
24.8	185	140	199	225	187.5	244	6.5	24.1
	201	156	216	240	203	259	7.1	25
24.8	258	192	296	288	237	335	8.1	27.4
24.9	223	169	247	242	215.5	285.5	7.1	26.2
25.2	191	147.8	212	231	195	256	6.51	24.6
24.2	168.5	131	179	210.5	178.5	226	5.9	23.5
24	145	117.5	155.5	188	164.5	203.5	5.3	23.3
24	135	105	137	178	151	195	4.7	23.6
23.7	123.2	99.2	116	166	144.8	164	4.1	22.9
23.3	111.5	81	100	153.5	123	147	3.5	22.2

Data 7.

Came at 7:00 A. M. and found the top of test tube No. 3 broken. This was probably caused by strain upon it from the collar in which it was held. I readjusted the level of Hg. in the neg electrode so that its surface was about 1 1/2 cm lower than before. This gives more room for measuring effect of distance above the surface.

At 4:15 P. M. when operating the lamp on a 9.1 Amp current the head of casing No. 3 got hot enough to allow the pressure from the outside to blow a hole therein. It was necessary to take the tube down and fix it. In a half hour, however, the tube was again ready to exhaust.

Distance of junctions from surface, 1 1/2 cm.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	.104	74	97	145	114.8	143	3.52	22.3
23	112.5	87.2	115	145.6	131	165	4.06	23
23.7	133	96	141	176	142.5	189.4	4.68	23.4
23.9	137	106	144	180	152	192.5	4.81	23.8
24.5	148.5	115	170	191.5	162	217	5.43	23.7
24.	155	128.5	199	198	176	244	6.00	24.5
24.7	215.5	146	228	252.5	193.5	269.8	6.58	25.8
25.5	260	167	272	289.4	214	306	7.01	27.5
25.8	296	189	320	317	234	343	7.6	30
26.5	355	223.5	393	361	264.8	397.5	8.08	33
25.5	414	260	472	402	295	452	8.54	38.5

Data 8.

I let the pump run for 2 1/2 hours last night. When I came this morning I ran it for about ten minutes and in starting the arc found it to be all right.

Started the pump at 7:10 and turned on the light at 7:15. It was O. K.

At 859 reading 3 fell off suddenly about ten divisions and then came back quickly to 838. Possibly a leak.

Lamp goes out at 3.4 Amperes.

Tested for leakage by suddenly breaking the lamp circuit. Could find no effect.

Distance of junctions from surface, 2 cm.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
21.3	102	85	126	143	128	174	3.58	22
21.7	113	101	145	155	146	193	4.01	21.8
22	126.5	114.8	168	169.5	162	215	4.7	21.8
22.3	172.6	155	229.2	214	202	270.2	5.91	23
22.8	201.1	185.4	273	240	230.5	307	6.51	24.3
23.5	290.1	255	289	313	290.8	394	7.6	28
25.1	300	285	435	320.5	314.2	427	5.97	29.2
25.8	295	265.2	400	317.[illegible]	299	402	7.5	28.5
25	240.2	228.1	338	375	268	356	6.9	26.8
25	176	173	242	217	219	281.5	5.7	23.8

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
24.6	155	146.2	208.8	198	194	253	5.1	23
24.2	131	129	185	174	177	231.5	4.5	23.5
24	116	113.5	156	158	160	204	4	23
24	103	97	118.1	144	142	167	3.35	22.7

Beginning at 4 P. M. Saturday I took out the thermo junction No. 2 from its casing and replaced it in a new casing taking particular pains that the wires did not touch near the junction where the insulation had been burned off of the copper wire. In putting the junction in the new casing the platinum wire broke again at about the same place where it had broken before. I soldered it again. In replacing the junction I separated the uninsulated part near the junction with asbastos. My reason for removing it in the first place was that I feared a short circuit had been formed and that probably I was not getting the correct readings.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	112	111	166.5	154	157.5	214	58.4	25
23	106	98	141	147	143	189	52.2	23.8
23.3	98	85	113	138	128	161	46.2	23.2
23	96	77	100	136	118	147	4.1	22.8
23	91	68	82	130	107	126	35.2	22.1

Data 9.

Starting switch was down while these readings were being taken, that is, while the first and second readings were being taken.

Distance of junctions above surface 2 cm.

Zero at 500

Data taken at 6 minute intervals.

Room t.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
22.7	107.2	88	113.2	149	132	160.5	3.51	23.8
23	109	89	138.2	151	133.2	187	4.1	23
23	124	108	170	167	154.2	217	4.71	23.4
23	135.8	124.5	200	179	172	245	5.26	23.6
24	164.8	139	220	207	187	263	5.86	23.3
23.6	157	256	236.4	204	293	293	6.35	24.4

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23.4	242	181	283	275	227	315.5	6.9	26.2
24	260	206	329	289.5	249	349.7	7.5	28
24.1	299	270	373	310	303	382.5	8.02	29.4
24	340	301	426	350	326.5	421.5	8.37	30.8
24	308	278	388	326	209	393.5	7.85	30
24	259	241	323	288.5	279.5	345	7.2	28
23.6	215	203	271	252	247	305	6.52	25.6
25.3	168.8	166	193	212	213	239	6.02	23.3
24	137	140	168	180	187.8	215.5	5.3	22.7
23.5	125	129	142	168	126.8	190	4.68	23
23	116	112	122	158.2	158	170	4.1	22.8
23.2	110	99	114	152	144	162	3.7	22.5

It is interesting to note here that at about 5 amp. the temp. of No. 2 is higher than No. 1 but at other points above and below it is lower.

Distance of junctions above surface, 3 cm.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature From curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	133	118	145	176	165	193.5	3.7	22.8
23.5	145	132.2	173.5	188	180	220.5	4.28	23.2
24	158.8	160	212	201.5	207	256	4.95	23.5
24.2	178	193	252.5	219	238	290	5.6	24
24	230	222	284	265	263	315.5	6.1	24.5
25.5	278	258	320.2	303.5	293	343	6.7	25.7
25.8	318	298	364	333.5	324	376	7.28	27.8
25.2	372	350	420	372.5	363	417	7.8	29
26	434	409	486.5	416	406	462.5	8.3	31
26.1	407	385	458	397	388.5	444	7.7	30.2
26	365	340.2	405	368	355	406	7.1	28.8
26	289	268	326	312	301.5	347	6.5	25.8
24.8	224	224	284	260	265	315.5	5.9	25
24.5	178	187	241	219	233.5	280.5	5.22	24.2
24.2	158	157	204	200.5	204	249	4.6	23.8
24.1	143	137	179	185.5	185	226	4.09	23.5
24	137	120	150	199.5	176	198.5	3.5	23.2

Data 11.

Distance of junctions above surface, 3 1/2 cm.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	141	136	151	184	185.5	199	3.63	23.4
23.5	151	159	180	194	206	227	4.20	23.8
23.5	170	183	213	212	229.5	257	4.63	23.9
24	200.2	211	252	239	254	290	5.25	24.1
23.5	229.8	247	288	264	284.8	319	5.82	24.6
24	292	277	322	314.5	308.5	344	6.42	25
24	329	319	364	342	340	376	6.96	26.2
24.2	378.2	373	417	377.5	380	415	7.5	28
24.3	426	431	472	410	424	453	8	30
24.8	458	478	513	432	452	479	8.3	32.5
24.8	439	453	494	419	436	467	7.8	30.8
24.8	396	411	449	393	407	438	7.3	29.5
24.6	340	384	380	349.8	351	387.8	6.7	27.4
24.4	288	284	317	311	321	340.5	6	28.4
23.2	205	227.5	260.2	243.5	268	296	5.26	24.5
23.5	176	192	223	217	237	265	4.6	24
23.8	152	164	186	195	211	232.5	4	23.8
23.8	139	143	159	182	191	207	3.54	23.3

Data 12.

The junctions 1 and 3 are now somewhat out of the axis of the tube and junction 2 is almost the opening of the condensing chamber.

Distance of junctions above surface, 4 cm.

Zero at 500

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
23	143.2	148	156.8	186	195.5	205	3.58	23.8
23	152	168	184.2	195	214.8	230.5	4.15	23.5
23	171	198	218	213	242.5	261	4.7	24
22.9	191	226	256	231	267	293	5.3	24.2
23	231.1	262	291	266	291.5	321	5.9	24.3
23	271	300	330	298	326	350	6.5	24.8
23	321	363	385	336	372.5	391	7.3	26.5
23	368	427	440.2	370	418	436.2	7.9	28.1
23	402.5	486.5	497.5	394	457	469	8.45	30
23.2	396	463	472	389.5	442.5	460	7.82	30
23.4	351	412	423.5	357.5	407.5	420	7.1	28.5
23	296	339	358.4	317.8	353.8	371.8	6.5	26.2
23.5	262	284.5	306	291	314.[illegible]	332.5	5.9	24.6
24	203	246	271.5	242	283.5	305.5	5.3	24.5
23.7	170	209	231	212	252	272	4.71	24.[illegible]
23.5	157	178.1	196.1	200	223	241.5	4.1	23.5
23	142	152	162	185	199	210	3.5	23.5

Data 13.

Distance of junctions from surface, 4 cm.

Zero at 500

Data taken at 6 minute intervals.

Room T.	Galvanometer Deflections in mm.			Temperature from curve			Amp.	Volts.
	#1	#2	#3	#1	#2	#3		
26.2	136	161	173	179	213.5	220	3.5	22.8
25.9	148.5	180.7	196	191.5	232.5	242	4.06	23.2
25.9	175	205.1	224	216	249	266	4.65	23.3
25.9	202	246	272	241	283.5	306	5.44	23.6
26.1	245	284	308	277	318.5	334	5.91	23.7
26.1	269	322	343.2	297	342	360.5	6.35	24.5
26.1	303	369	387	322.5	378	393	6.81	26
26.2	338	425	444	348	417	434	7.35	27.5
26.5	390	510	520	385	477	483	8.12	30.5
26.4	370	465	473	377	443.5	454	7.45	28.8
26	333	407	416	345	404	414	6.87	27.4
26.2	294.8	357	368	317	368	386	6.37	26
26.1	260.2	305	314	290	330	337	5.85	26.4
25.8	216	254	264	253	290	299	5.00	23.3
25.6	175	215	226	216	257	268	4.5	23.8
25.6	152	188	196.5	195	233.5	242	4	23.5
25.5							3.5	23

Data 14

Zero at 500.

Data taken at 5 minutes intervals.

Room T.	Temperature from curve			Amp.	Volts	Distance from surface in cm.		
	#1	#2	#3			#1	#2	#3
21.3	141	107	130	5	22.5	.5	.5	.5
21.4	152	123	161	5	22.5	1	1	1
21.6	173	165	231	5	23	2	2	2
21.6	197	212	266	5	23.2	3	3	3
21.6	207	252	274	5	23	4	4	4
21.5	201.5	263	263	5	23.01	4.5	4.5	4.5
21.5	205	274	264	5	23.1	4.5	5	4.5
31.6	200	273.5	268	5	23	4	5.5	4
21.4	204	207	266	5	23	3	6.5	3
21.5	180.4	262	230	5	23	2	7.5	2
21.5	143	239	130	5	23	.5	8.5	.5
21.6	145	117	141.5	6	23	.5	.5	.5
21.6	162	148	189.5	6	23.2	1	1	1
21.6	246.5	170.5	315	6	23.5	3	3	3
21.6	275	319	312	6	23.6	4.5	4.5	4.5
21.7	256.5	332.5	321	6	23.6	4	5.5	4
21.7	215	329	261	6	23.4	2	6.5	2
21.7	196	308	264	6	23	1.5	7.5	1.5
21.8	153	289	154.5	6	23	.5	8.5	.5
21.8	138.5	178	125	6	22.8	0	8.75	0

Data 15.

At 5 cm. No. 1 is within a couple of mm. of th glass.

Had a breadown at 2:15 P. M. caused by attempting to draw the junction No. 2 down. The cold mercury caused it to break and let in the air. I took the apparatus down and put junction No. 1 in place of No. 2 leaving no junction at all where No. 1 was. This will serve as a check in the work.

Zero at 500.

Data taken at 6 minute intervals.

Room T.	Temperature from curve			Amp.	Volts.	Distance from surface in cm.		
	#1	#2	#3			#1	#2	#3
22.5	111.5	98	128	7	24.1	0	0	0
24	150.5	136	167	7	25	.5	.5	.5
24.5	195	184	237.5	7	26	1	1	1
25	284	214	331.5	7	26.5	2	2	2
25.3	357.5	344	390	7	27.5	3	3	3
25.3	344	358	393	7	27.5	3.5	3.5	3.5
25.	356	379	388.5	7	27.5	4	4	4
24.8	357.	388	381	7	27.3	4.5	4.5	4.5
24.5	335	393	394	7	27	5	5	5
24.5	330	385	353.5	7	27	5	5.5	5.4
24.1	333	375.5	357	7	27	5	6.5	5.4
24.8	340	343	359.5	7	26.8	5	8	5.4
24.8	340	259	357	7	27.2	5	11	5.4

Data 16.

Arc started up decidedly well before pump was started. After pumping about 15 minutes it was all right.

Zero at 500

Data taken at 6 minute intervals.

Room T.	Temperature from curve.		Amp.	Volts	J 2, 1.	J 3.
	#1	#2				
21	113.5	130.	4	22.4	1	1
21	143	173.5	4	22.5	2	2
21.3	185	207	4	22.4	3	3
21.3	203.5	213.5	4	22.5	3.5	3.5
21.6	224	219	4	22.5	4	4
21.6	234.5	219	4	22.6	4.5	4.5
21.6	240	209	4	22.5	5	5
21.7	239.5	209	4	22.5	5.5	5
21.9	213	210.5	4	22.5	7.5	5
21.7	128	152.5	3.5	22	2	2
22	152.5	186.5	4.5	22.7	2	2
23	167.2	218	5	22.8	2	2
23	207	261	6	24.3	2	2

Data 17.

After waiting all day for the D C. we finally got it at 9:00 P. M.

Zero at 500.

Data taken at 5 minute intervals.

Room T.	Temperature from curve. #1	#2	Amp.	Volts	J 2, 1.	J 3.
22	169	190	3.5	22.6	3	3
22.2	182.5	209	4	23	3	3
23.8	219	255	5	23.5	3	3
23.8	261.5	313	6	24.8	3	3
24	314.2	374	7	26.6	3	3
24.3	359.5	434	8	29	3	3.5
24	333.5	401	7	28.2	3	3.5
23.7	295	351	6	26.3	3	3.5
24	228.5	270	5	24.1	3	3
23	182.5	204	3.5	23	3	3
23.7	246	295.5	6	24	3	3
24	239.5	222	3.6	23	4	4
23.8	253	248.4	5	23.7	4	4
24.2	318	326	6	24.6	4	4
26	381	386	7	26.5	4	4
27.4	448	257	8	24.5	4	4
24	267	231.5	3.5	23.7	5	5
24	282	265	5	24.8	5	5
25.5	398	370	7	28	5	5

We will here keep the current constant at 4 amperes and vary the distance. This will show the variation of the temperature with the distance from the surface.

Zero at 500.

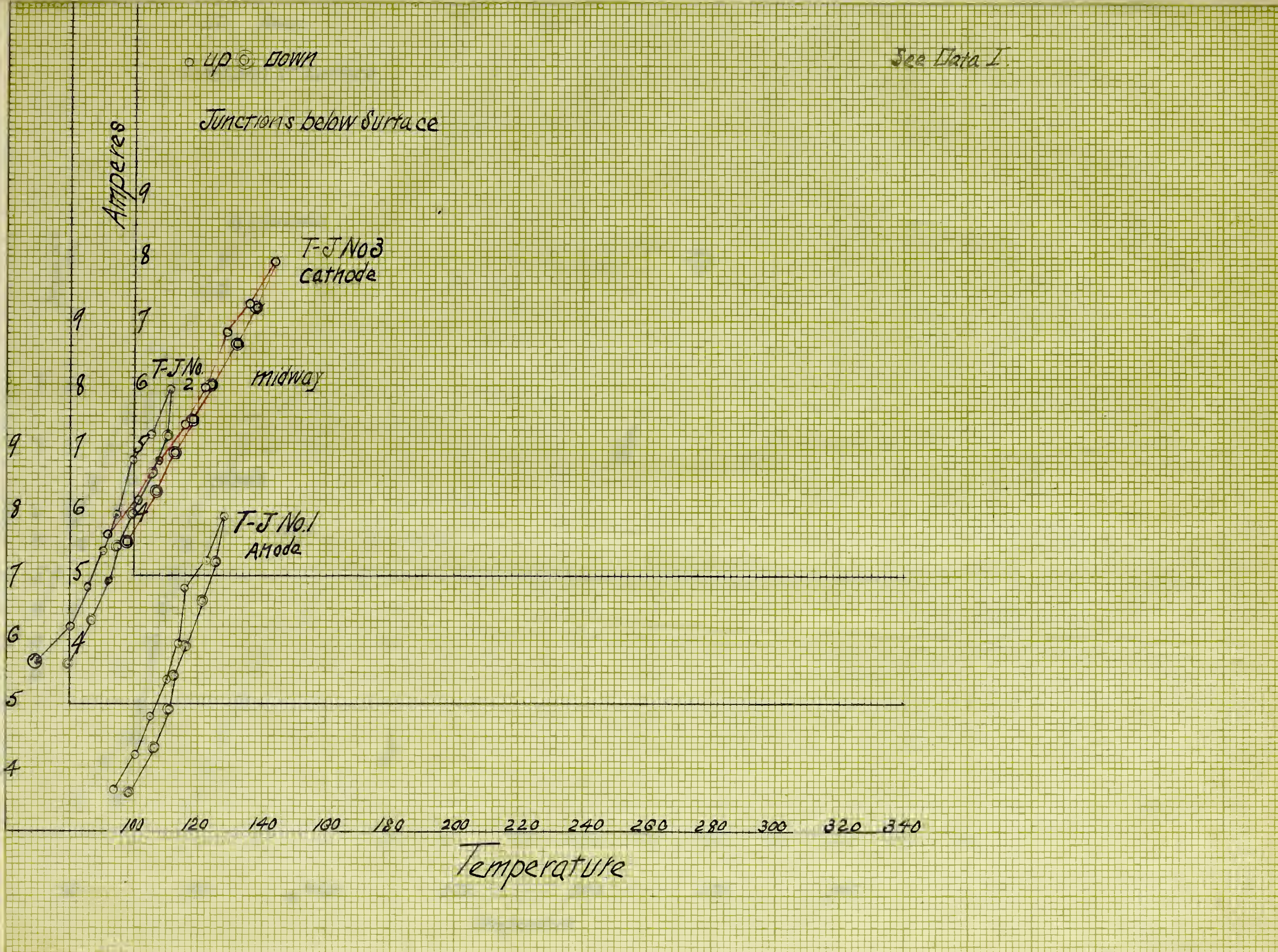
Data taken at 6 minute intervals.

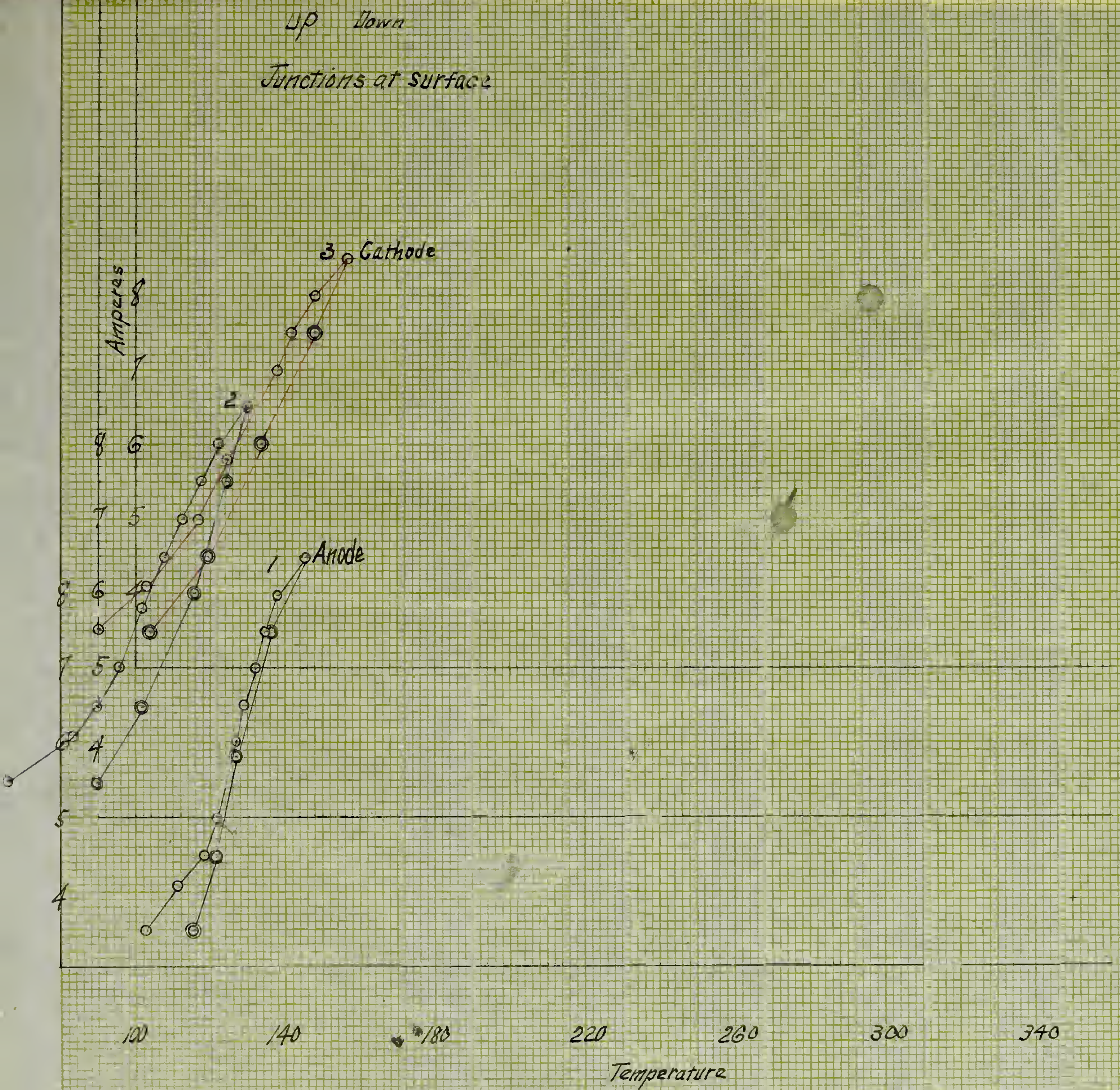
Room T.	Temperature from curve			Amp.	Volts.	Distance from surface in cm.		
	#1	#2	#3			#1	#2	#3
22.2	132.2	97	113	4	22	.5	.5	.5
22	150	112	136	4	22.4	1	1	1
22.3	156	128	160	4	22.5	1.5	1.5	1.5
22.1	165	136	173	4	22.5	1.75	1.75	1.75
22.5	165.2	146.5	186	4	22.5	2	2	2
22.3	185	190	212	4	22.5	3	3	3
22.5	183	216.5	224	4	22.6	4	4	4
22.1	183	240	224	4	22.6	4	5	4
21.3	181	226	226	4	22.6	4	6	4
22	180.	222	232.5	4	23	4	7	4
22	180	204.5	230	4	23	4	8	4
22	182	191	230	4	23	4	9	4
22	183	183	230.5	4	23	4	10	4
22	184	178	229.5	4	23	4	11	4
20	174	217	210	4	22.6	4.5	4.5	4.5
20	180.2	210.5	226	4	27.6	4	4	4
21.2	167	184.5	218	4	22.5	3	3	3
21.2	157.5	147	192.5	4	22.5	2	2	2
21.4	143	137	137	4	21.9	1	1	1

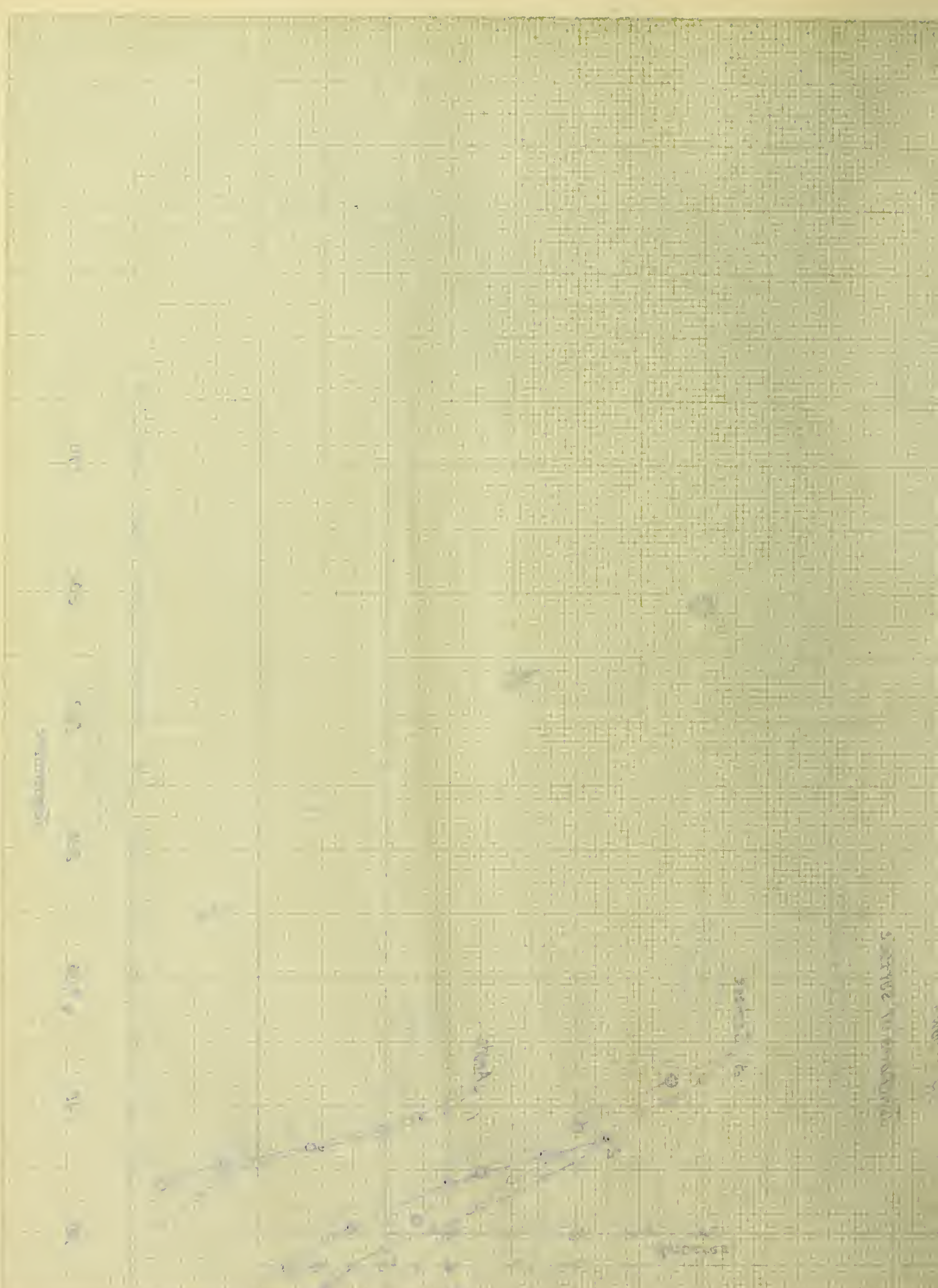
Calibration Data 19.

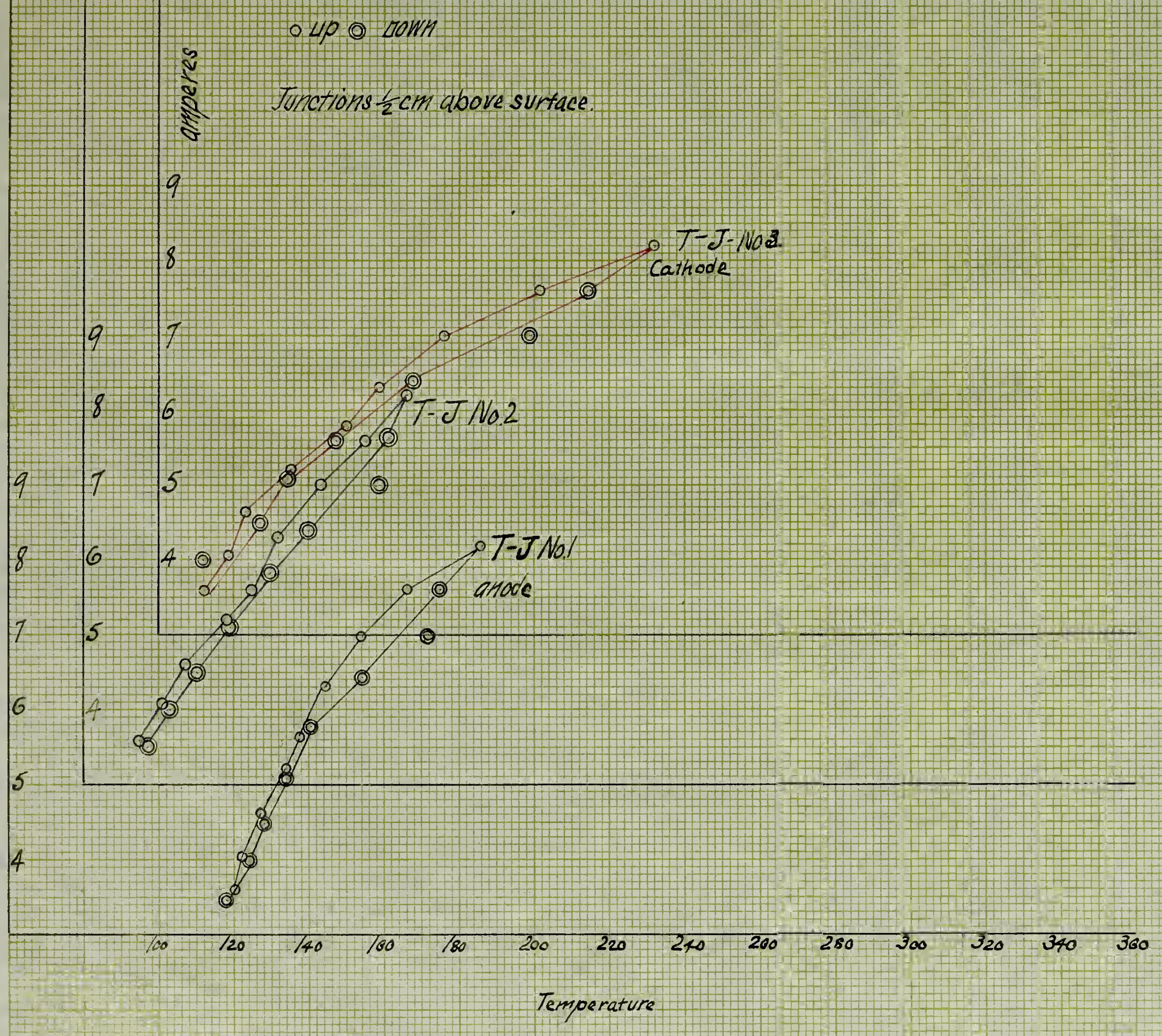
Zero at 500.

Time.	Room T.	Thermometer readings	Galvanometer deflections J 1.	J 2.	J 3.
3:50	22.5	212	66.5	61.6	61.9
4:30	22.4	230	74.5	71.9	69.8
4:42	22.4	260	89	85.7	83.7
4:50	22.3	280	99	95.5	93.2
5:35	22	304	110.9	107	104.2
5.55	21.8	328	123.5	119.5	117
6.15	21.8	344	132.2	128.2	127
6.35	22	372.2	148	143.3	142
7.05	22.1	390	158	153.2	152.1
7.25	22.2	418	174	168.9	167.9
7:35	22.2	440	187.2	181	180.5
7:55	22.7	464	201.9	197	194.3
805	22.8	490	217.9	212	210
8:15	22.2	510	230.6	224.1	222.6
8:30	22.8	540	249.7	244	241.2
8:55	22.6	572	277.9	264.8	262
9:05	22.6	610	297.1	290.1	288.9
9:15	22.5	638	317	310.2	307.9

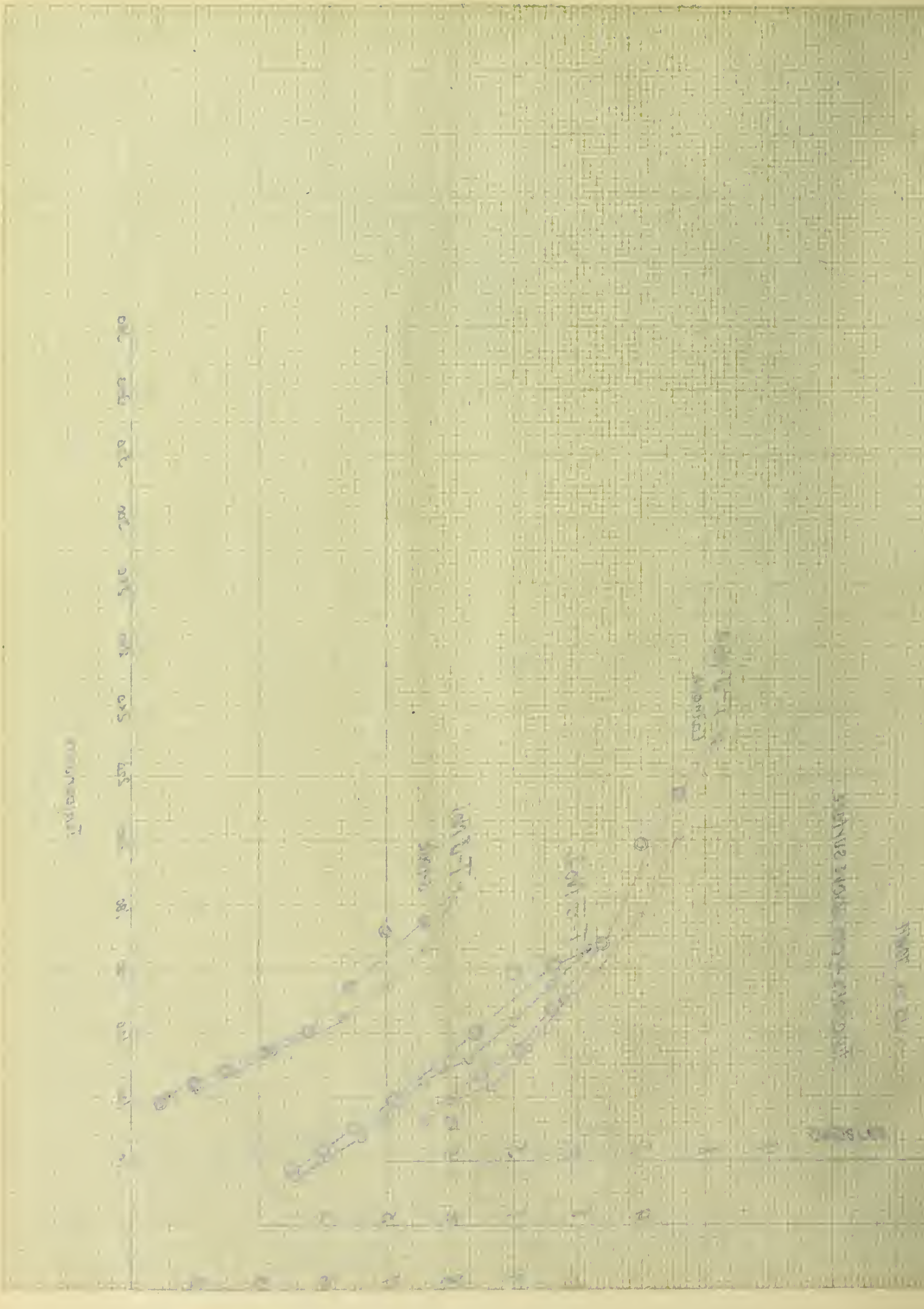

up
down
See Data I.
Junctions below Surface
Amperes
T-J No3
cathode
T-J No. 2
midway
T-J No.1
Anode
9
8
7
6
5
4
100
120
140
160
180
200
220
240
260
280
300
320
340
Temperature

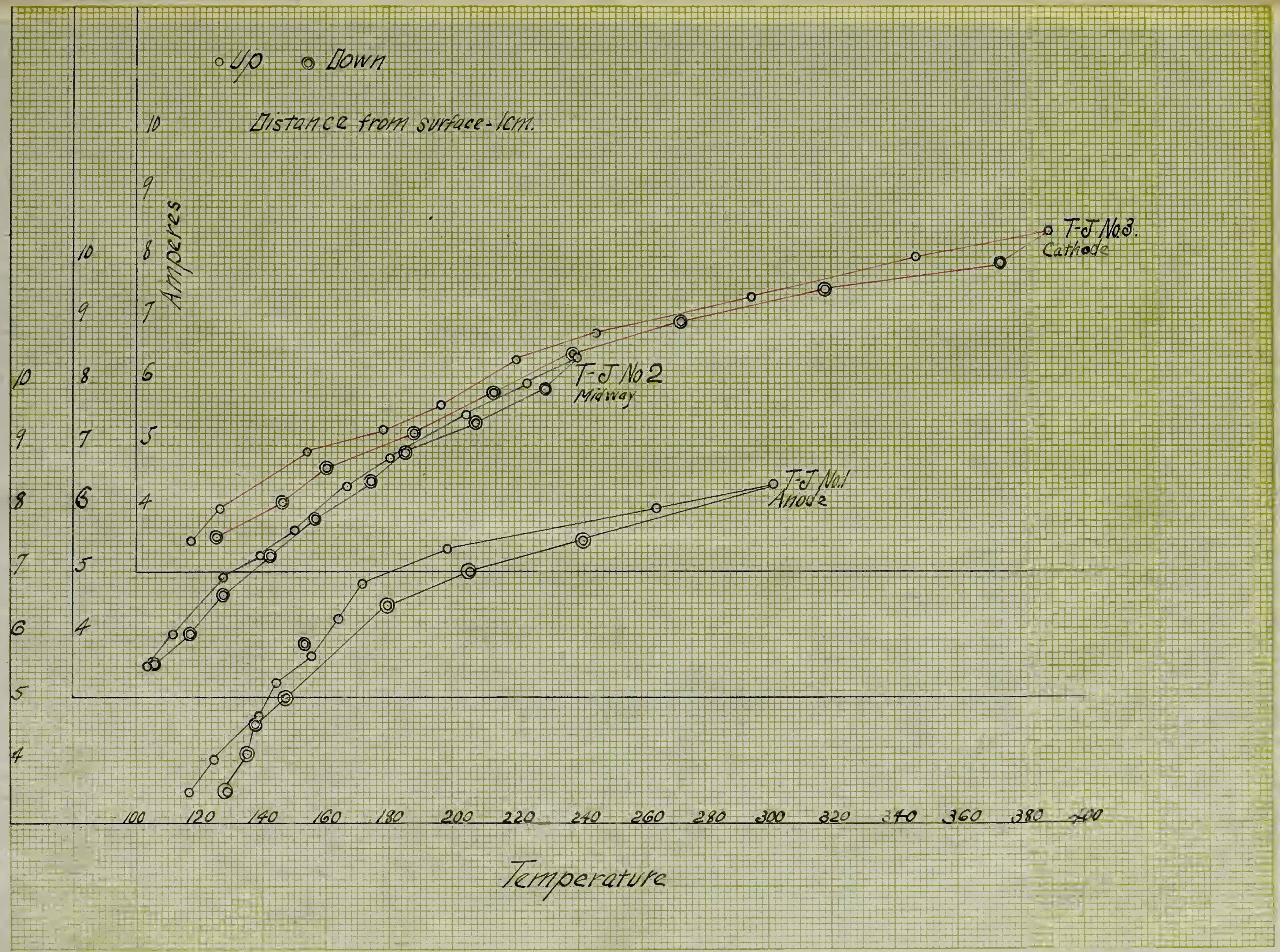

Up Down
Junctions at surface
3 Cathode
2
1 Anode
Amperes
8
7
6
5
4
100
140
180
220
260
300
340
Temperature



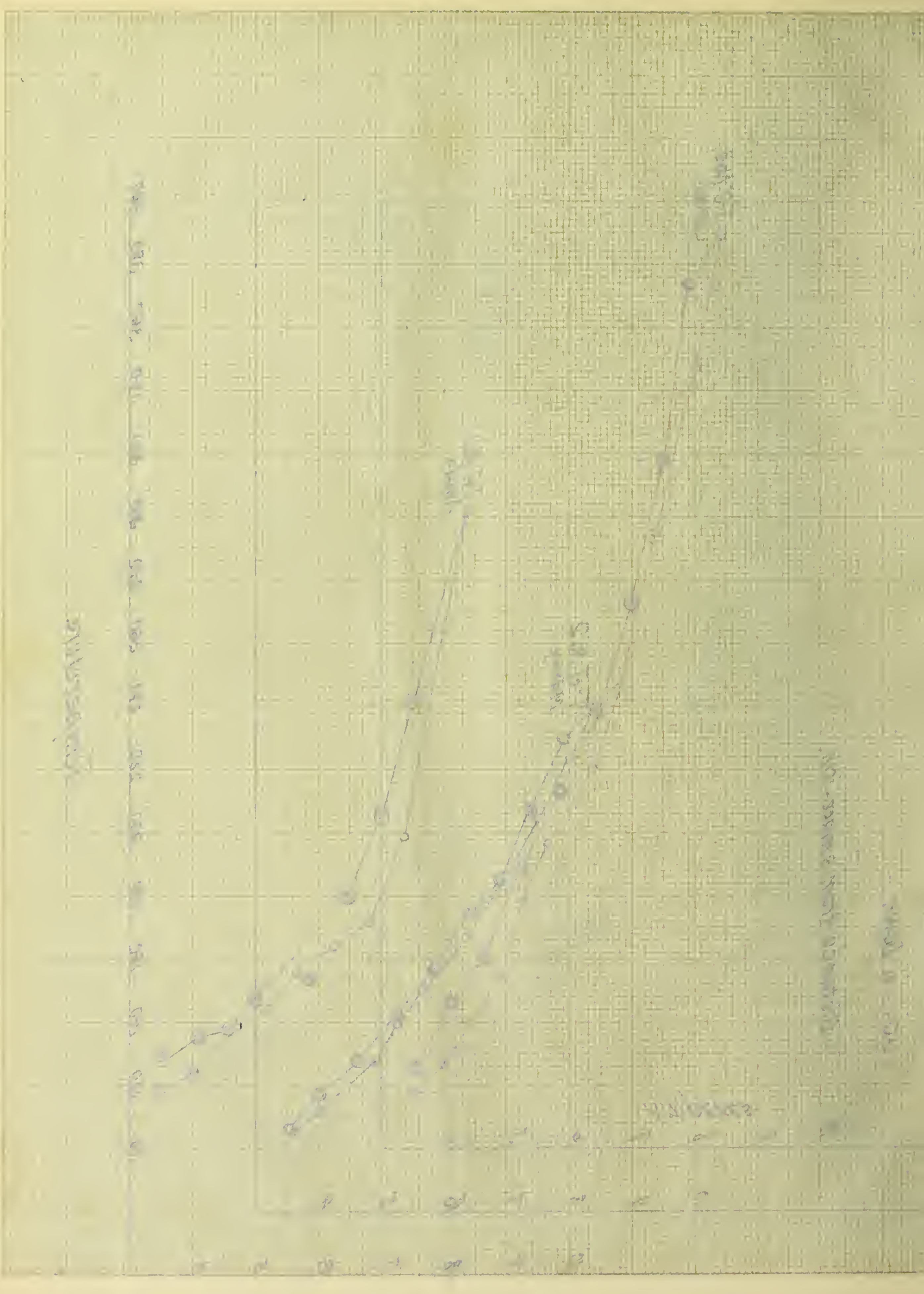


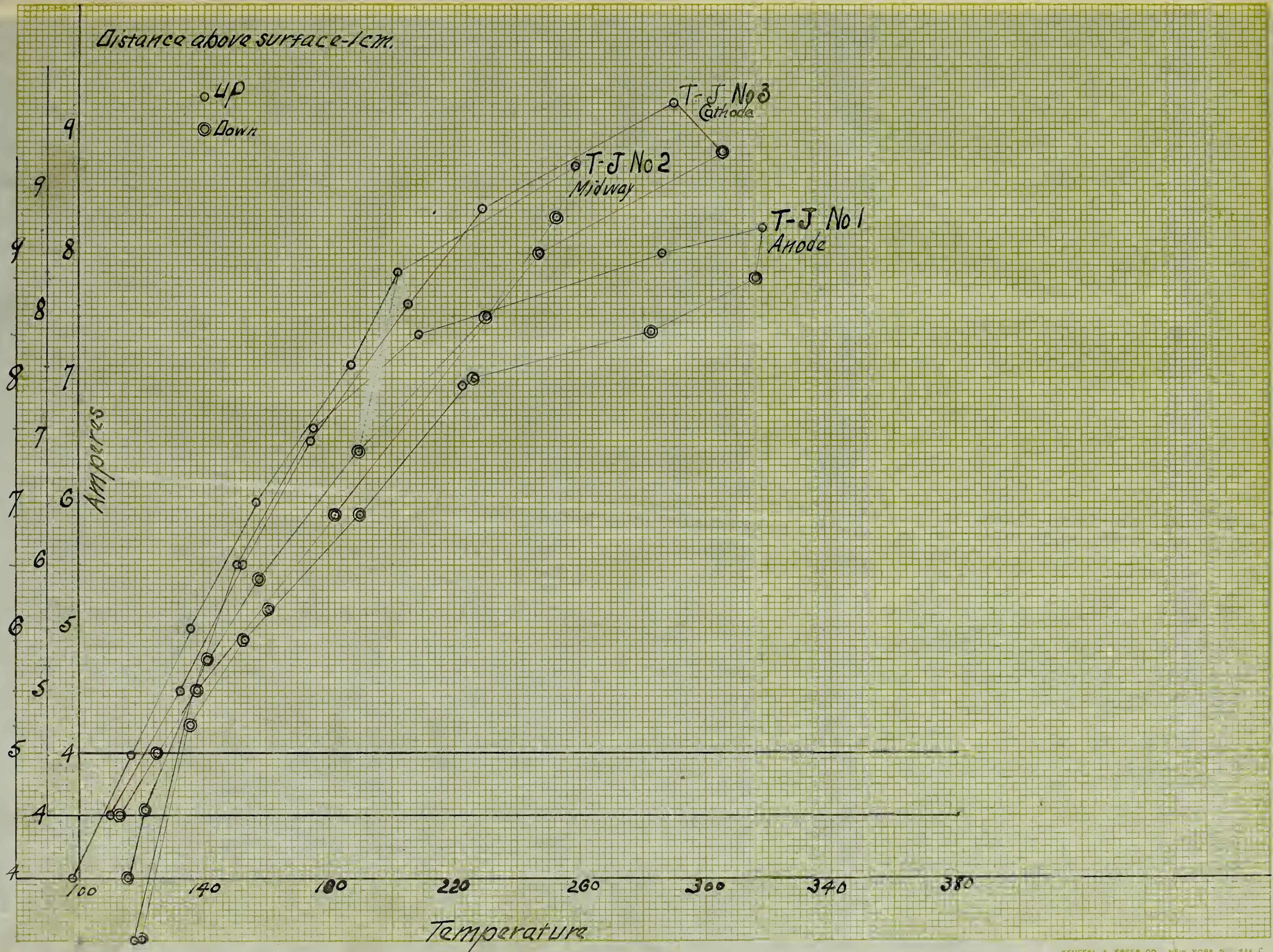
○ up ◎ down
Junctions ½ cm above surface.
amperes
T-J-No3
Cathode
T-J No2
T-J No1
anode
100
120
140
160
180
200
220
240
260
280
300
320
340
360
Temperature



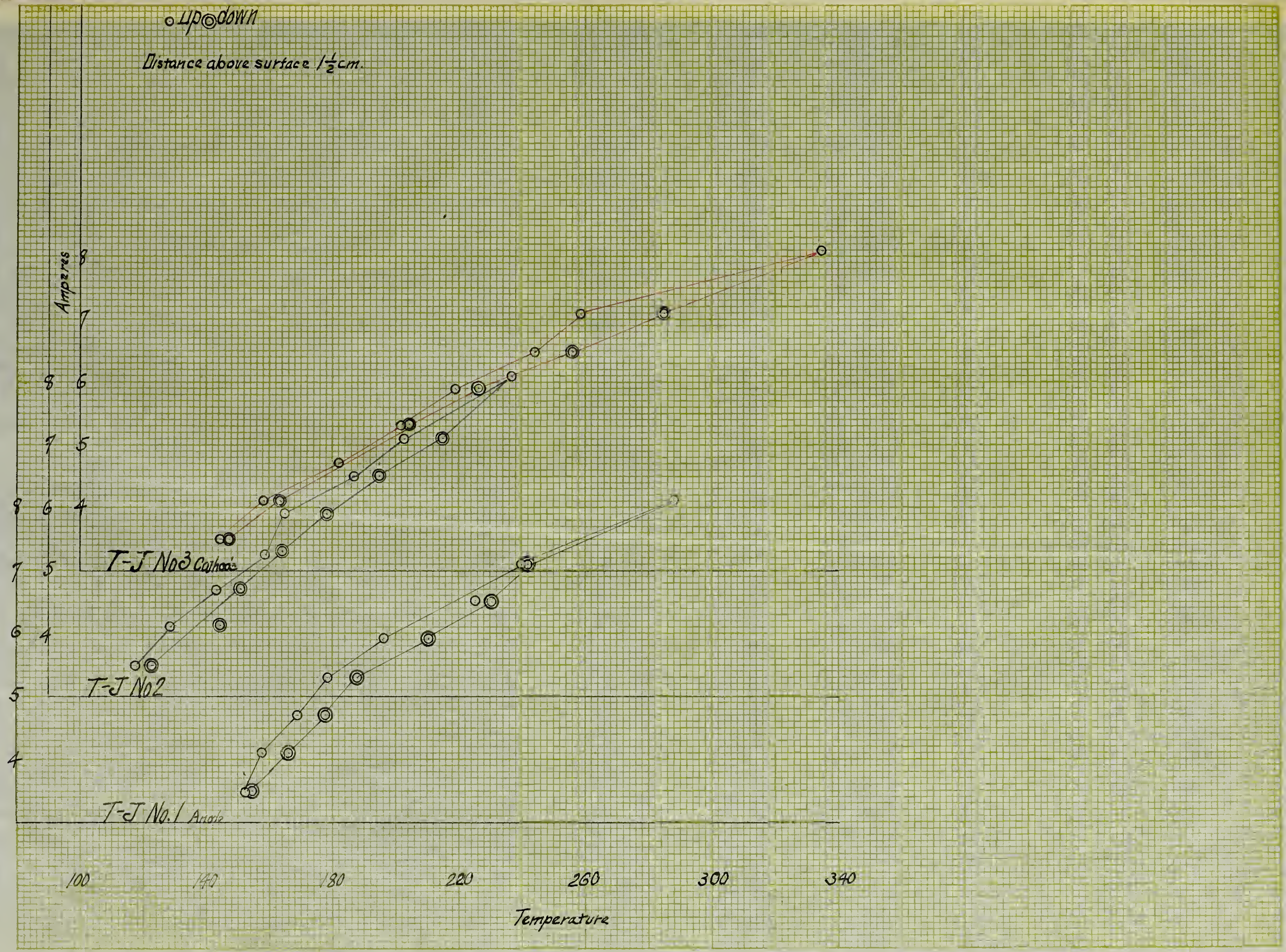


Up
Down
Distance from surface-1cm.
Amperes
T-J No 3.
Cathode
T-J No 2
Midway
T-J No.1
Anode
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
Temperature

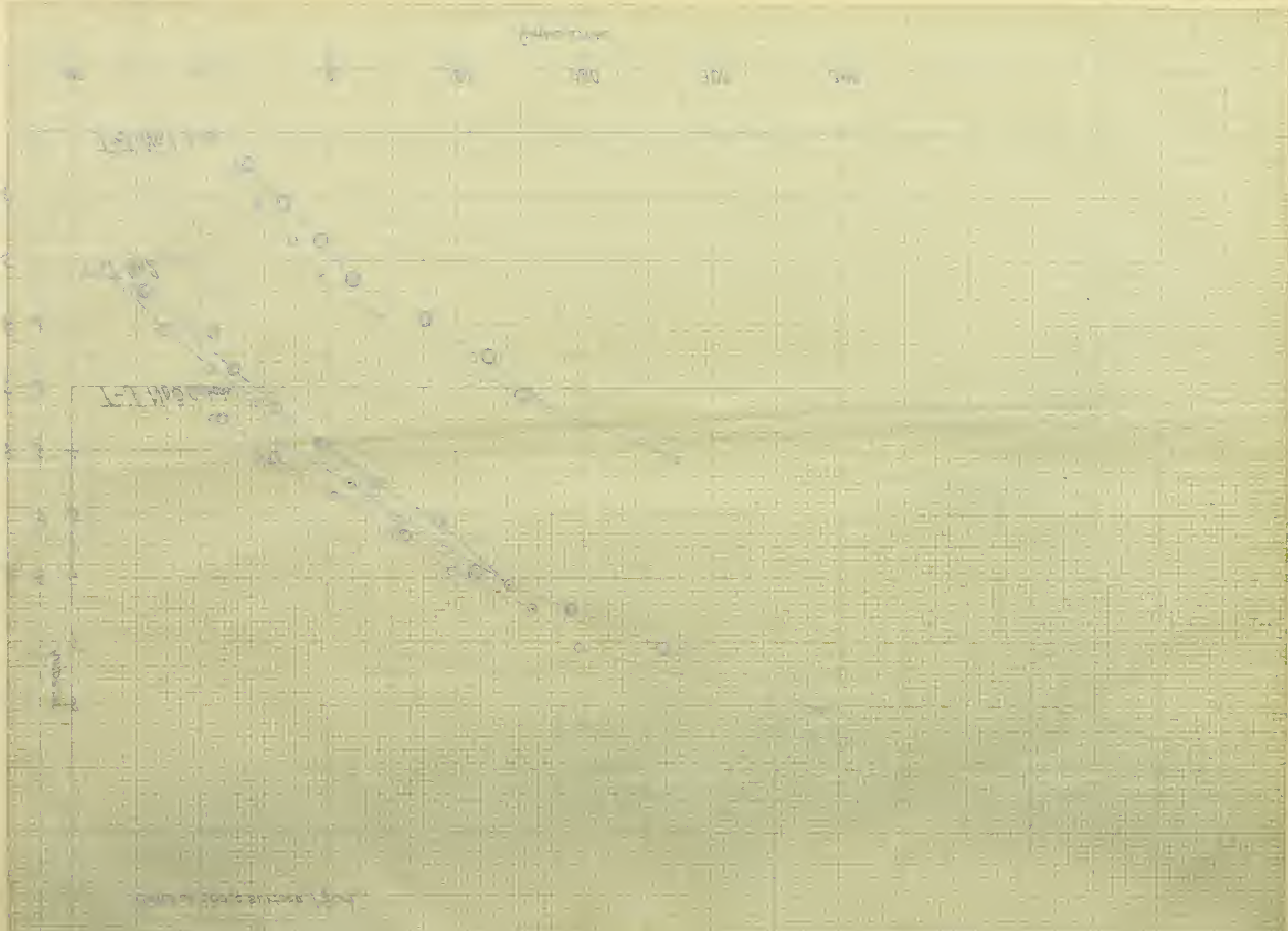


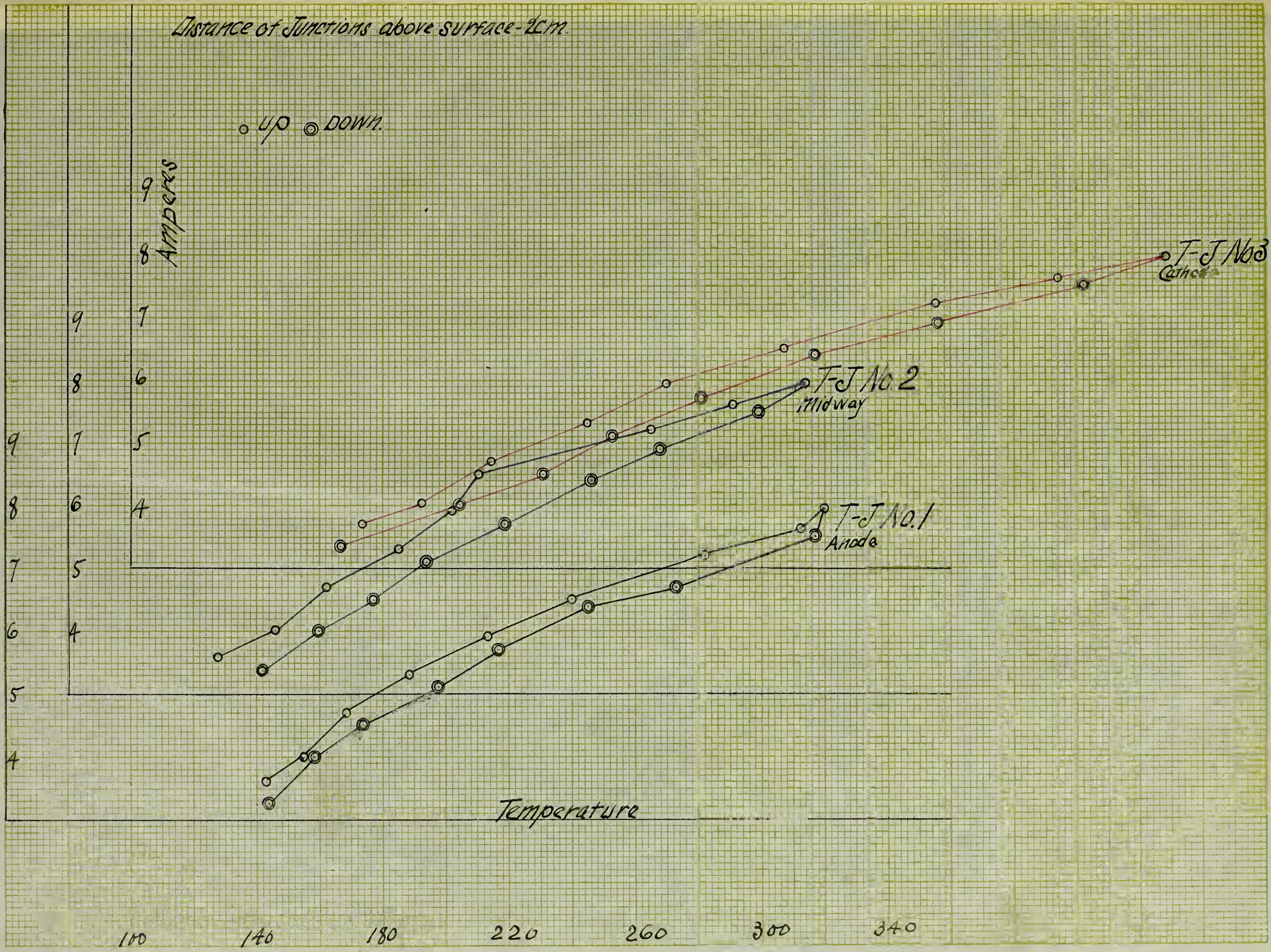


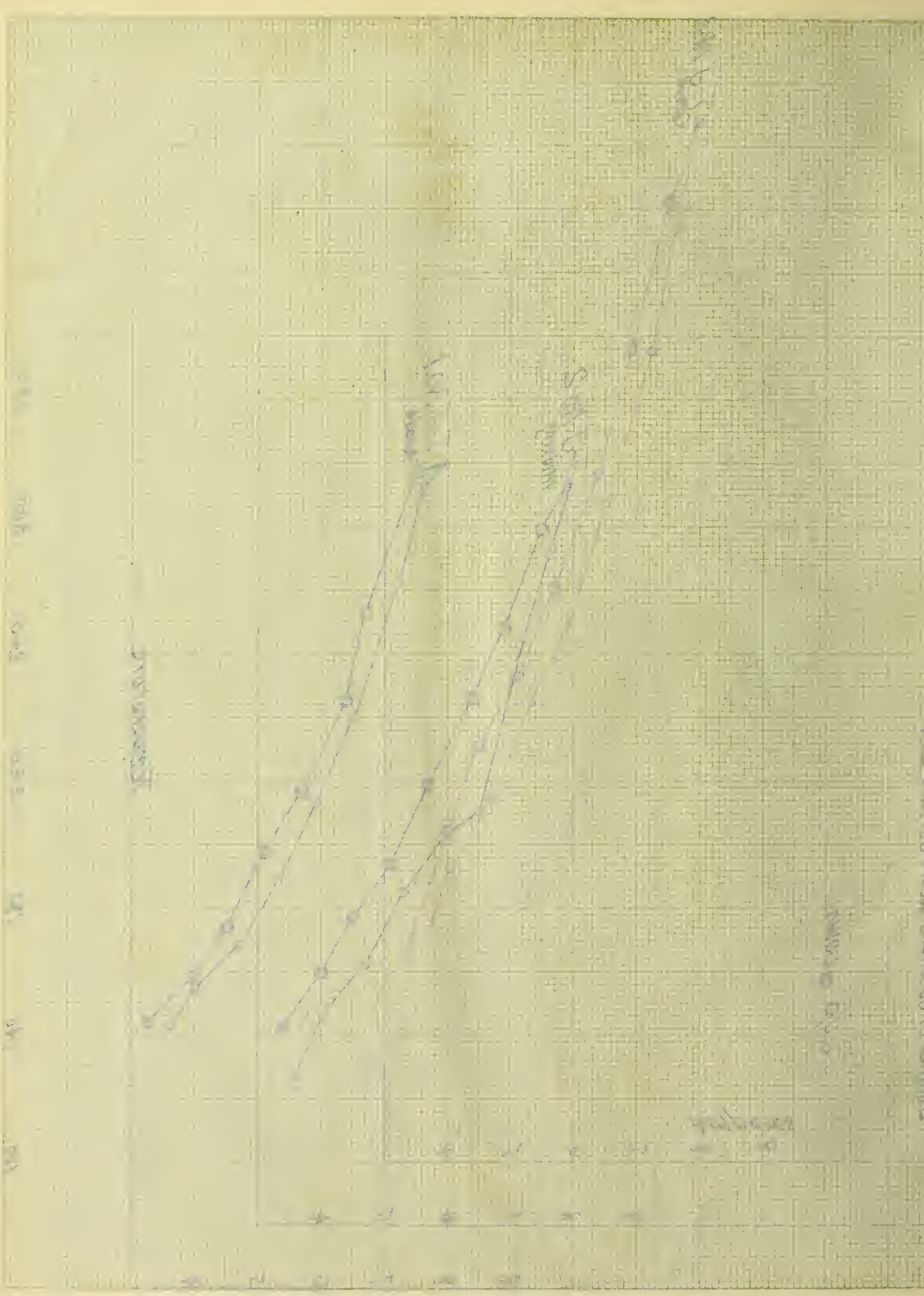
Distance above surface-1cm.
Up
Down
T-J No 3
Cathode
T-J No 2
Midway
T-J No 1
Anode
Amperes
Temperature
100
140
180
220
260
300
340
380
KEUFFEL & ESSER CO., NEW YORK NO. 334 C

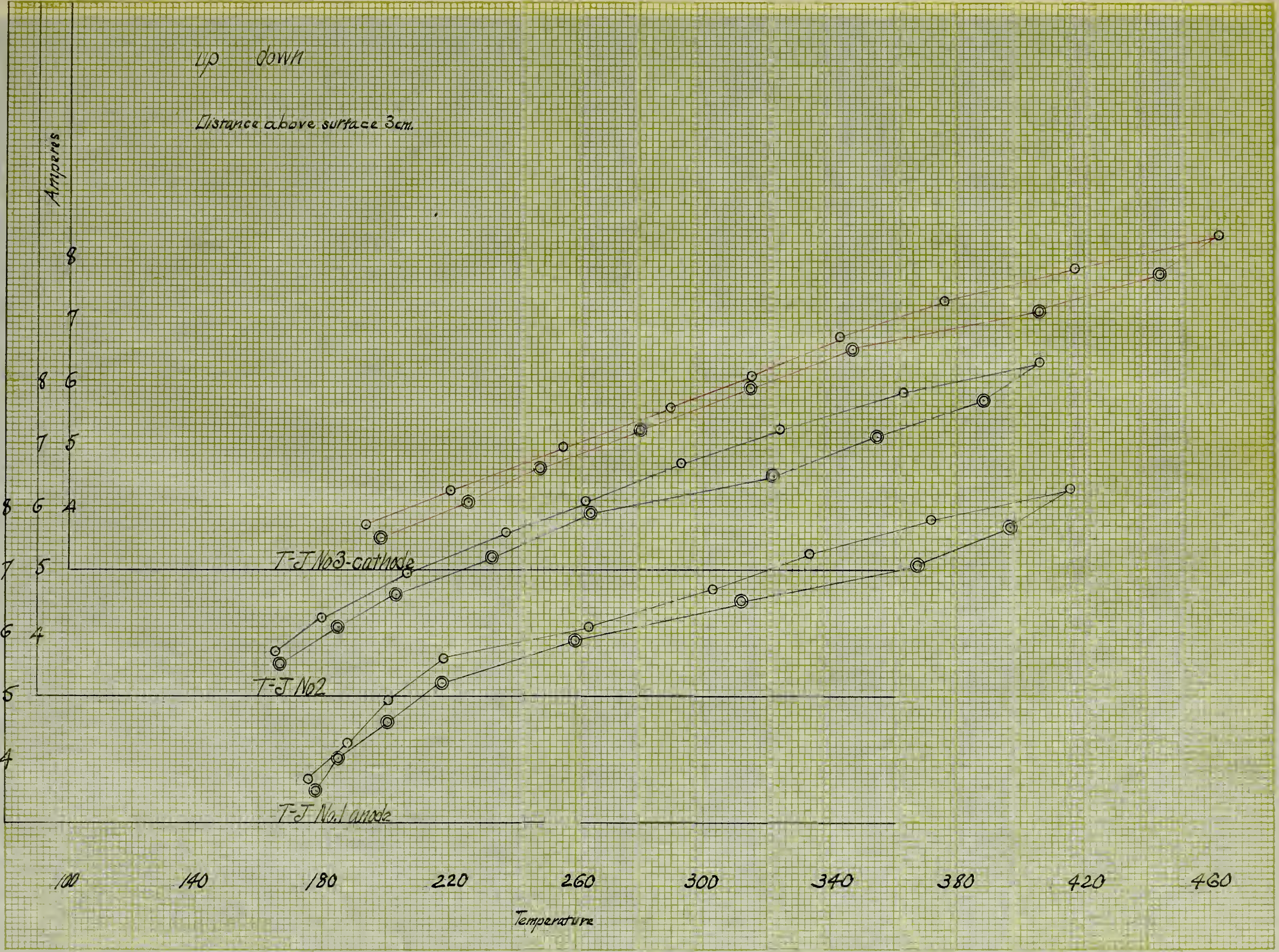


o up ◎ down
Distance above surface 1/2 cm.
Amperes
8
7
6
5
4
T-J No3 Cathode
T-J No2
T-J No.1 Anode
100
140
180
220
260
300
340
Temperature

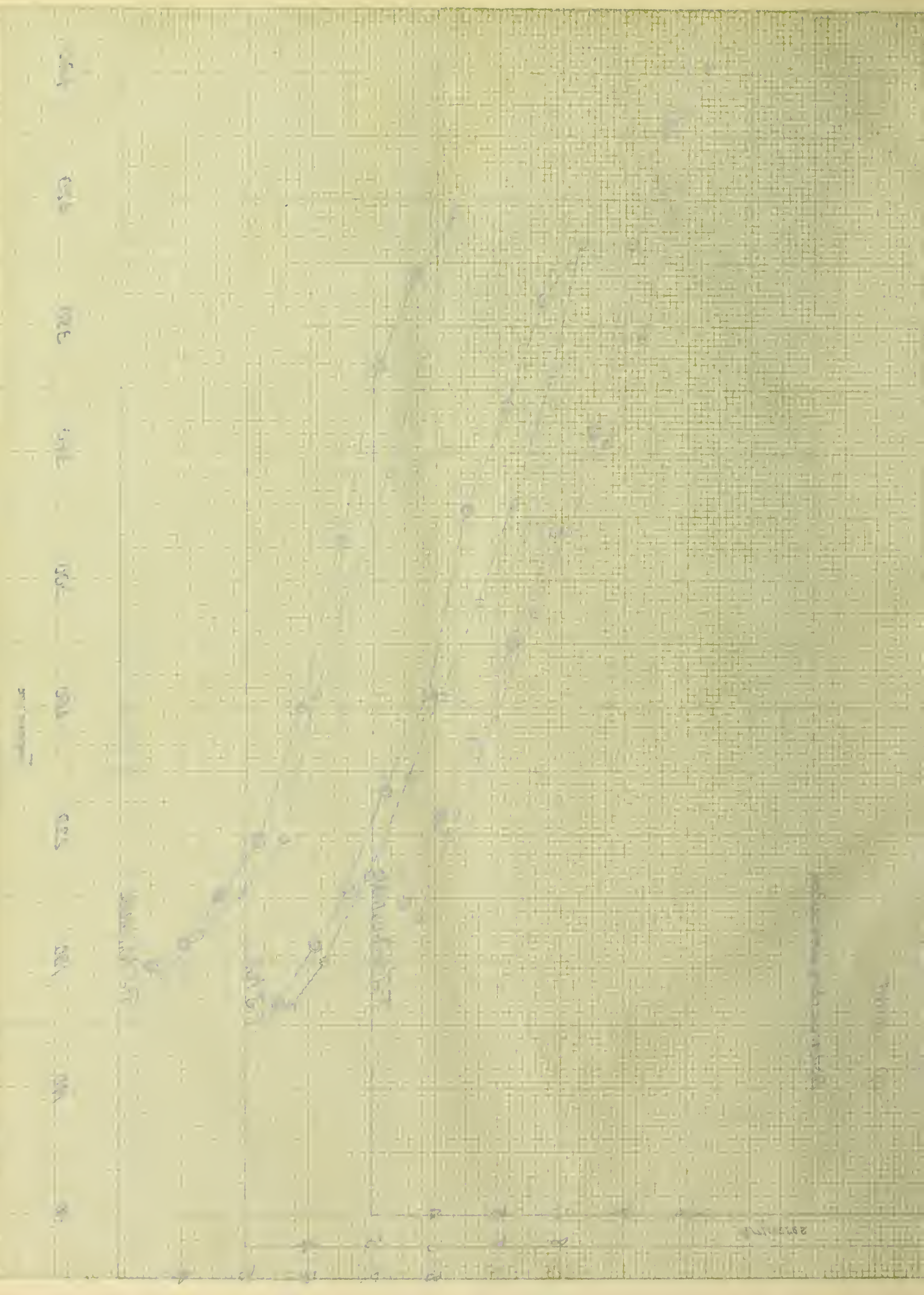


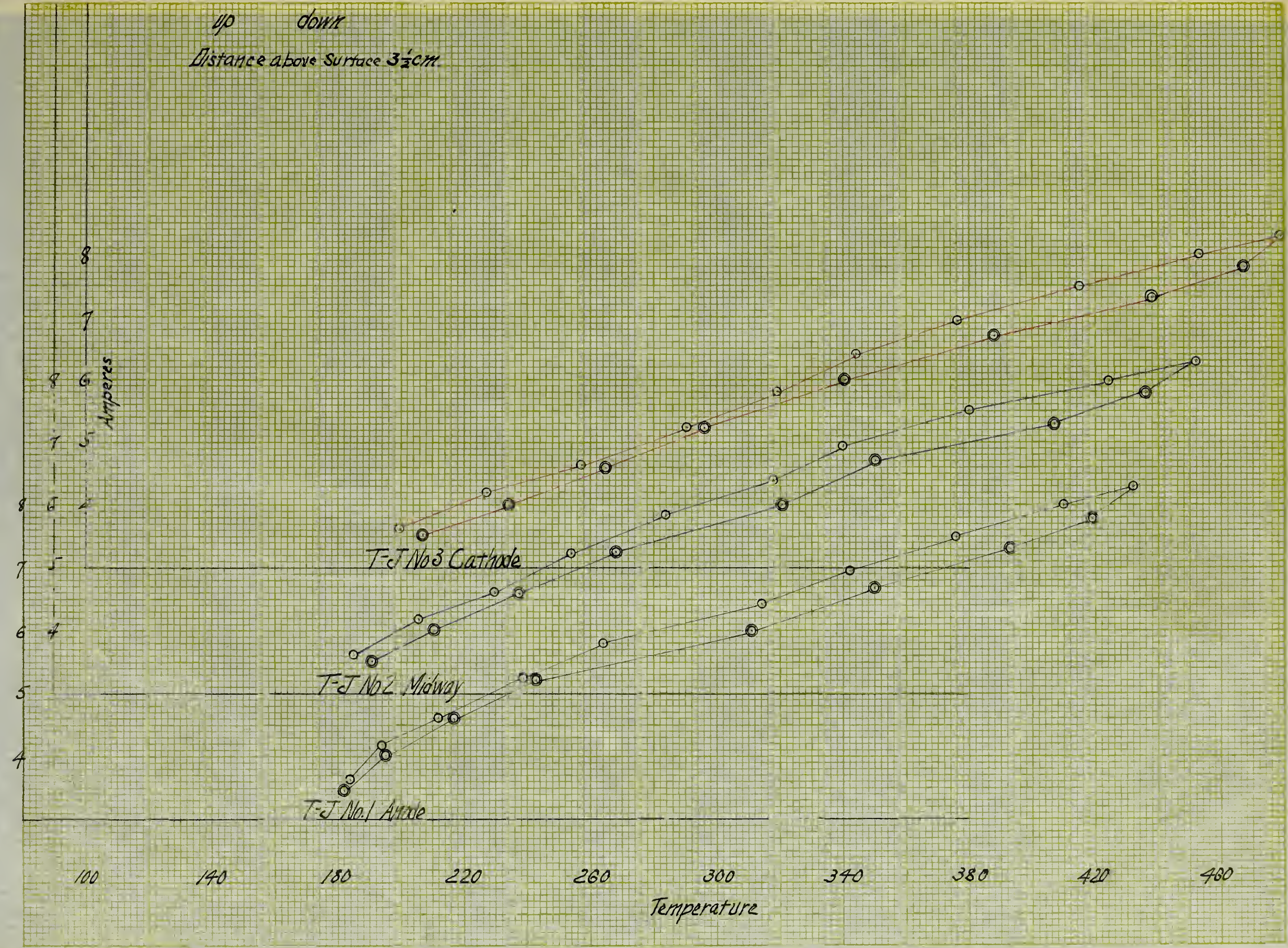

Distance of Junctions above surface-2cm.
up
down.
Amperes
T-J No.3
Cathode
T-J No. 2
Midway
T-J No. 1
Anode
Temperature
100
140
180
220
260
300
340



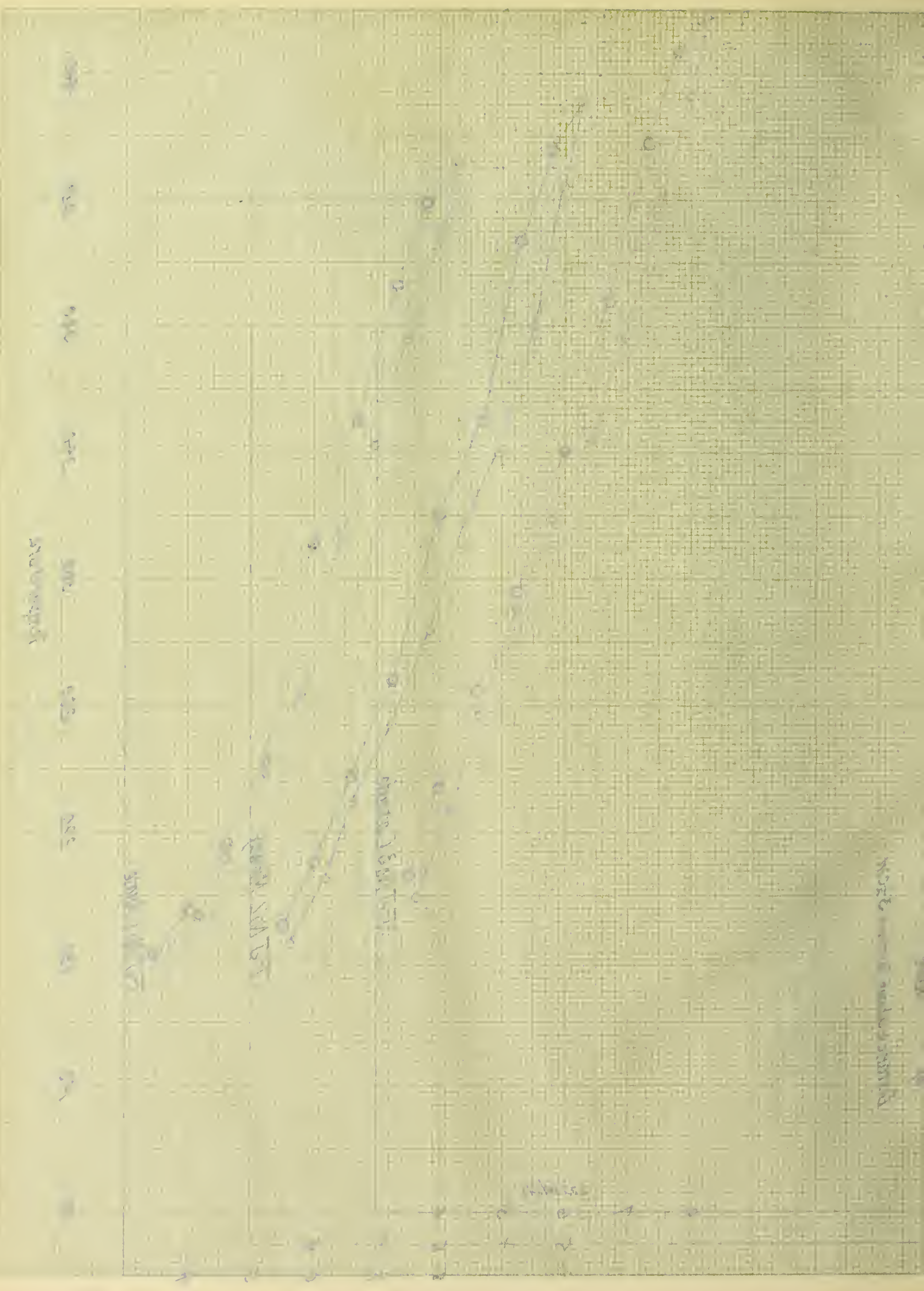


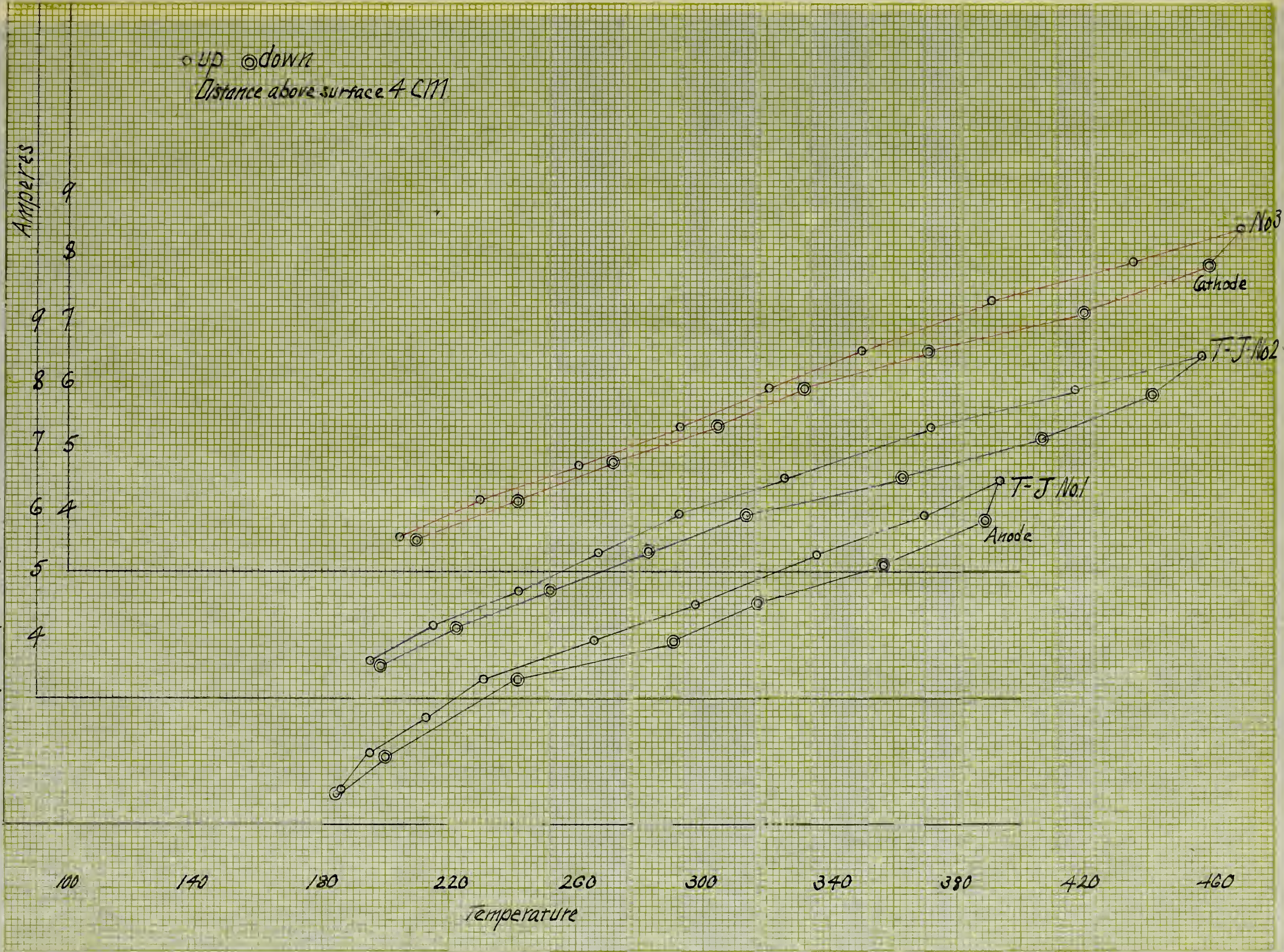
KEUFFEL & ESSER CO., NEW YORK NO. 334 C.



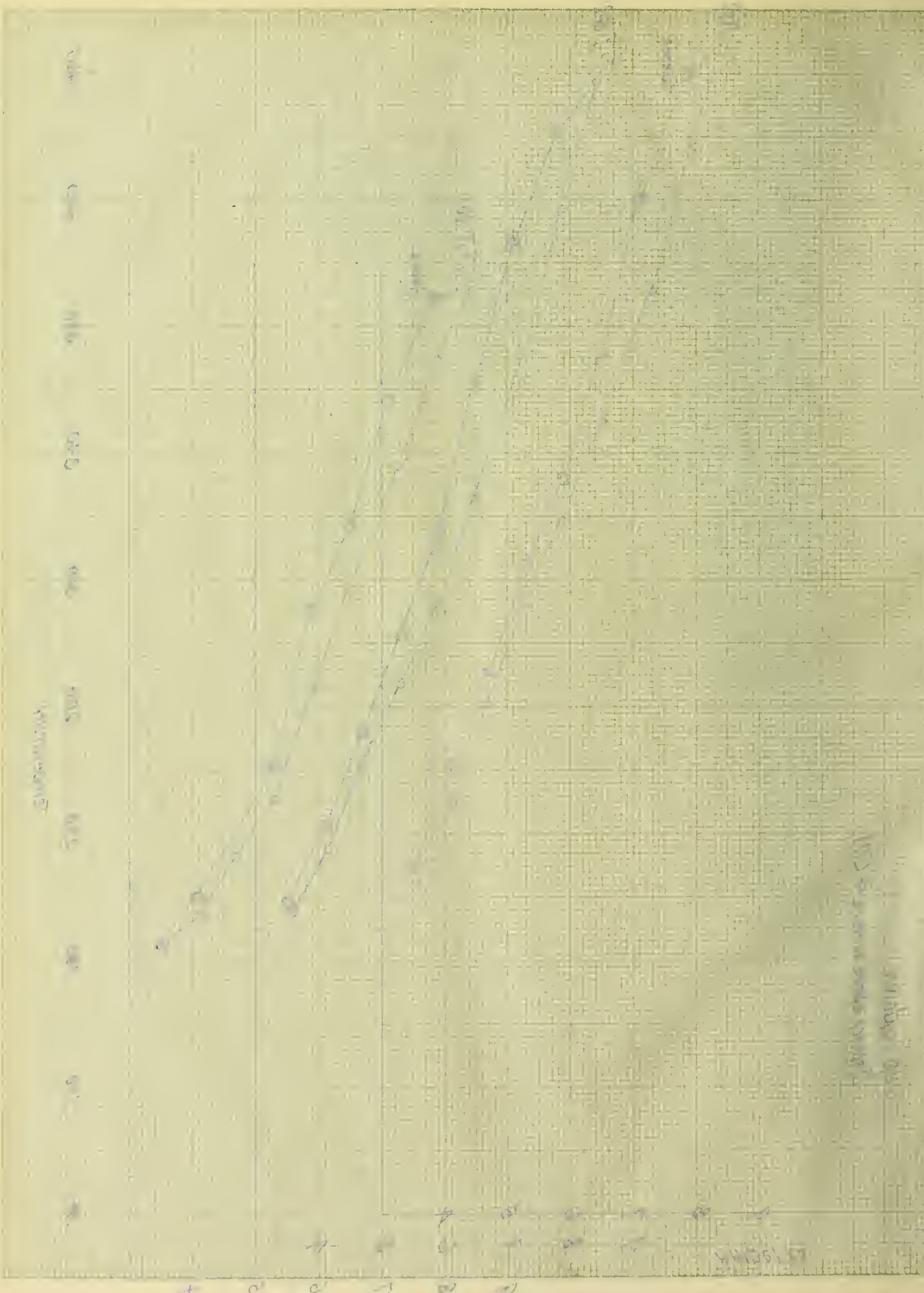


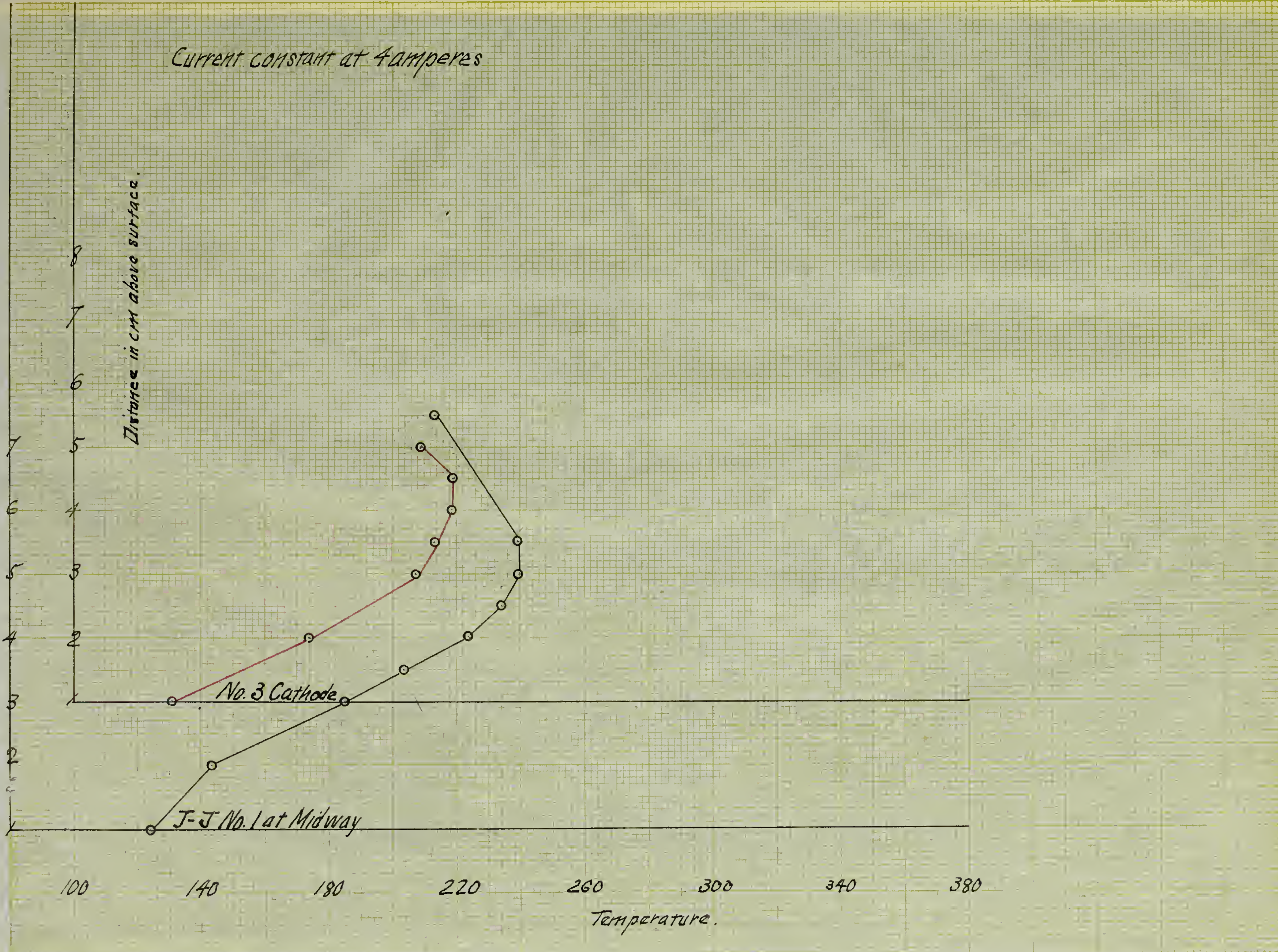
KEUFFEL & ESSER CO. NEW YORK NO 334



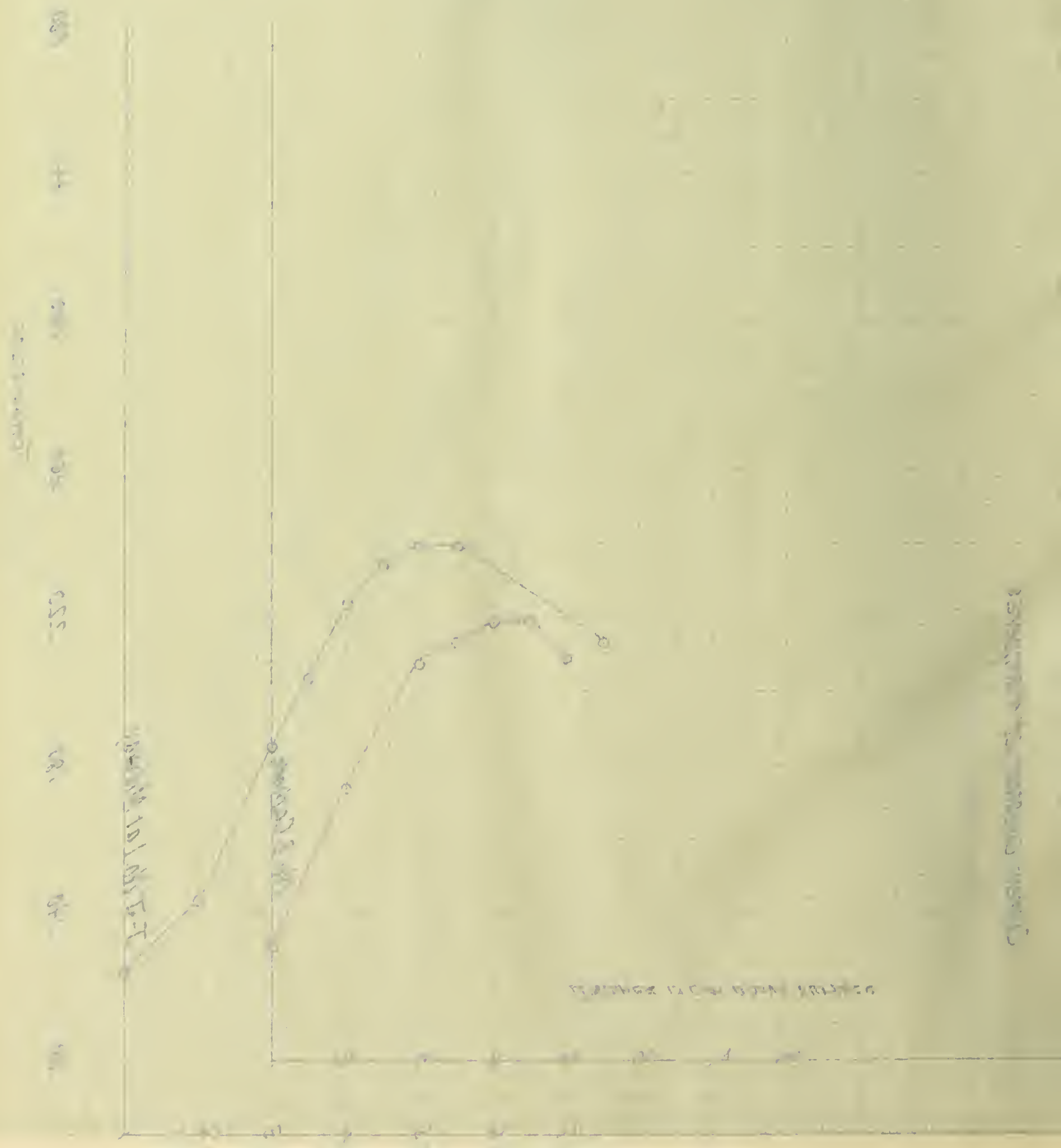


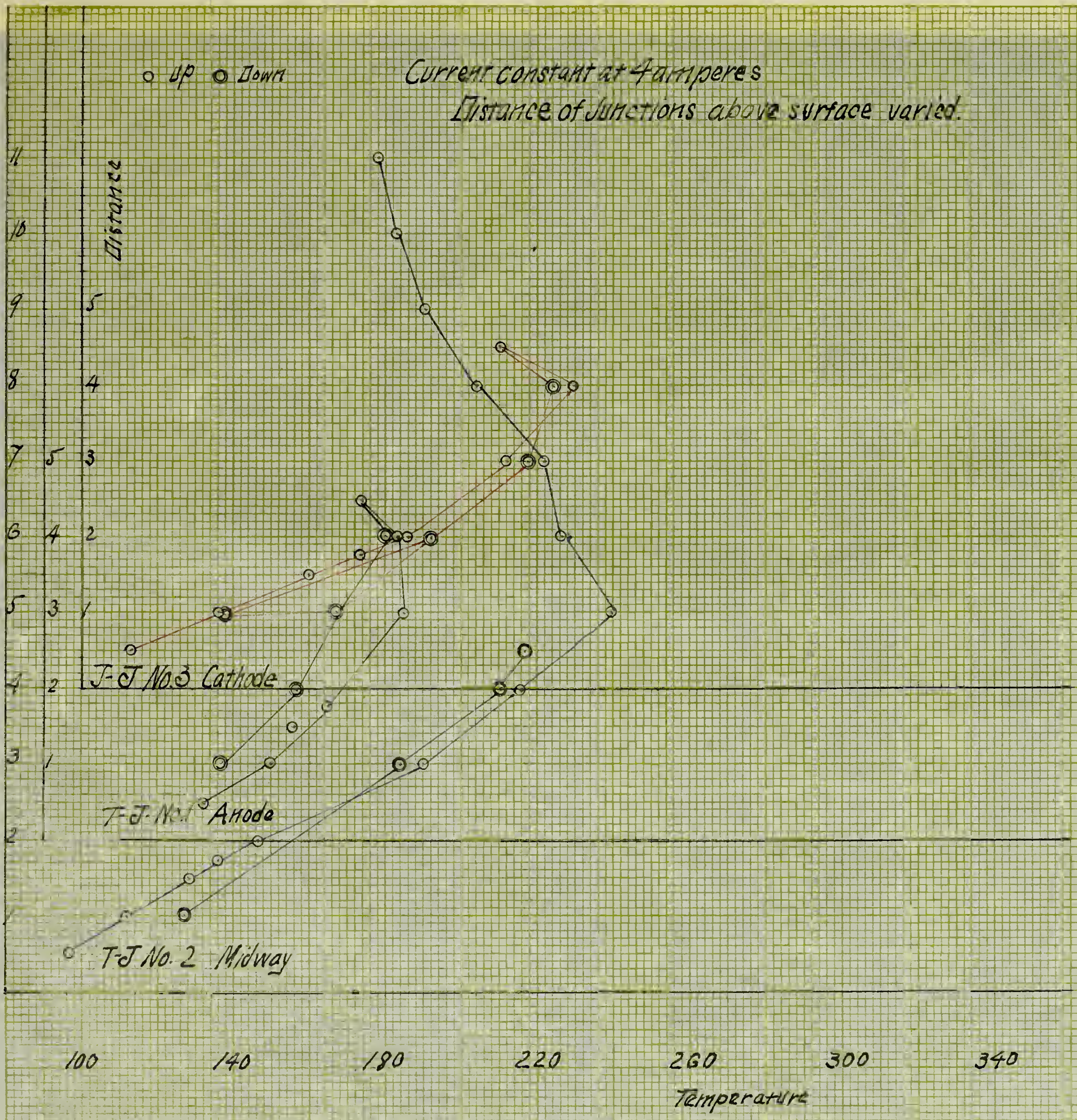
KEUFFEL & ESSER CO., NEW YORK NO. 354 C.

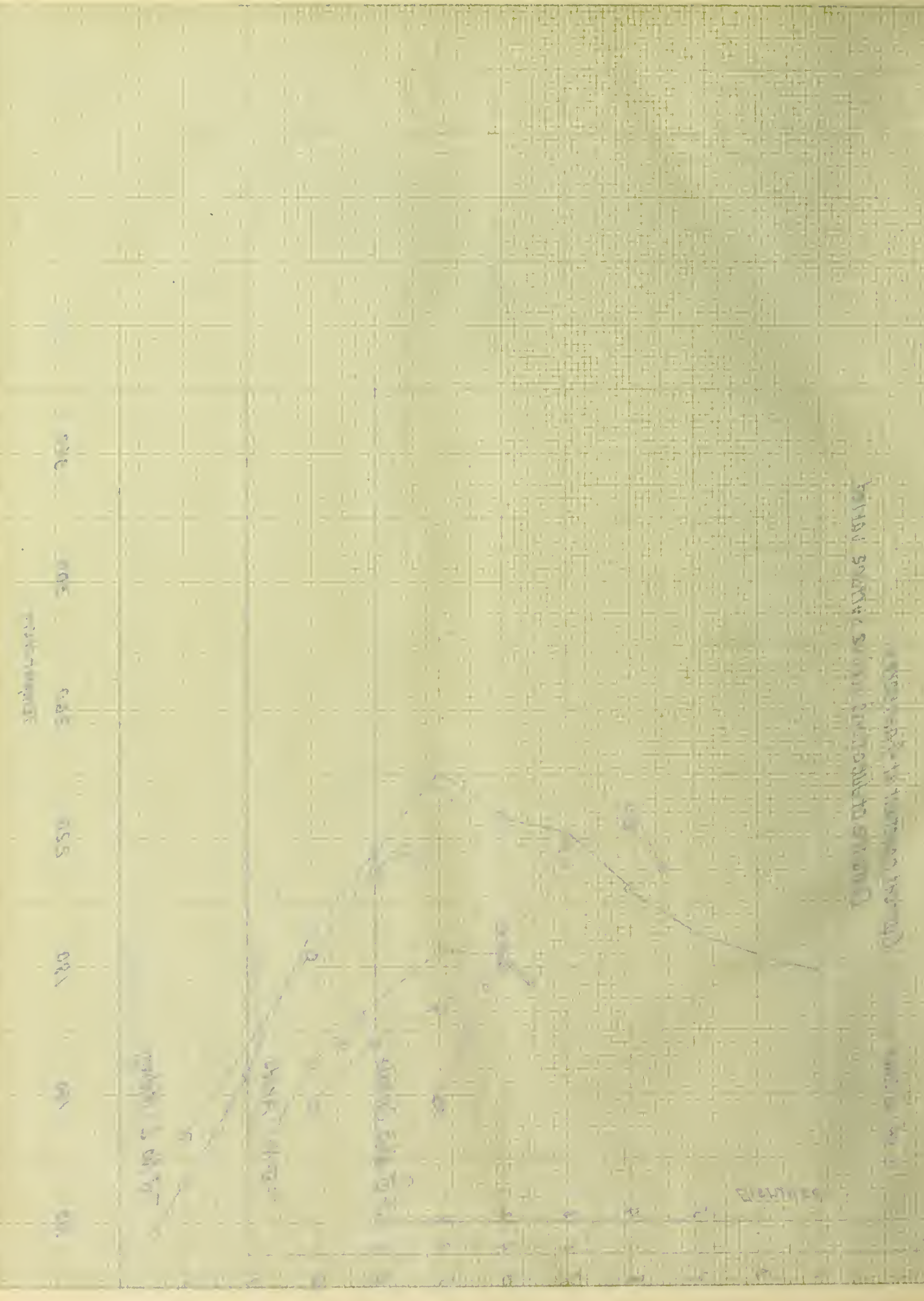


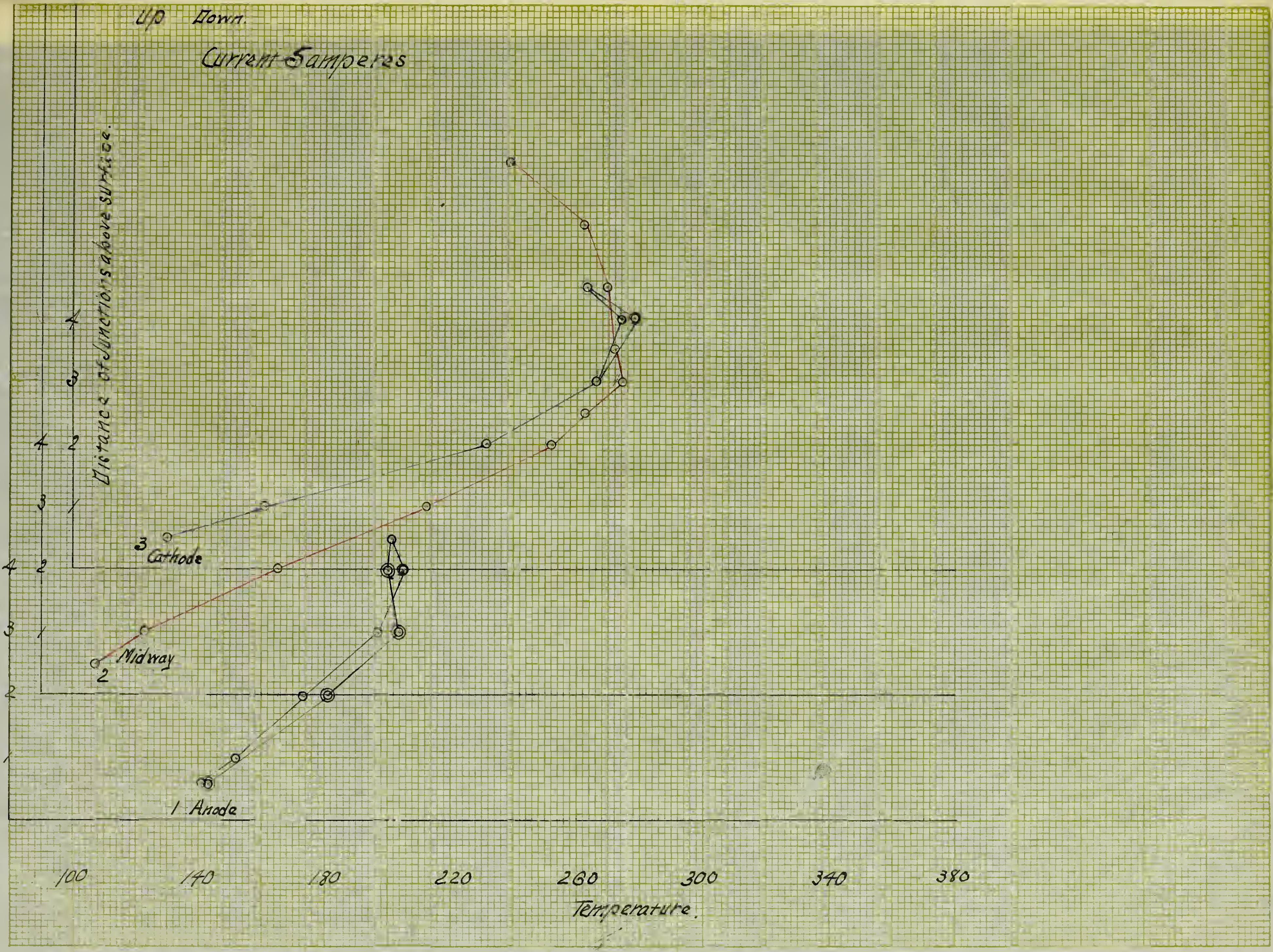


Current constant at 4 amperes
Distance in cm above surface.
No. 3 Cathode
J-J No. 1 at Midway
100
140
180
220
260
300
340
380
Temperature.

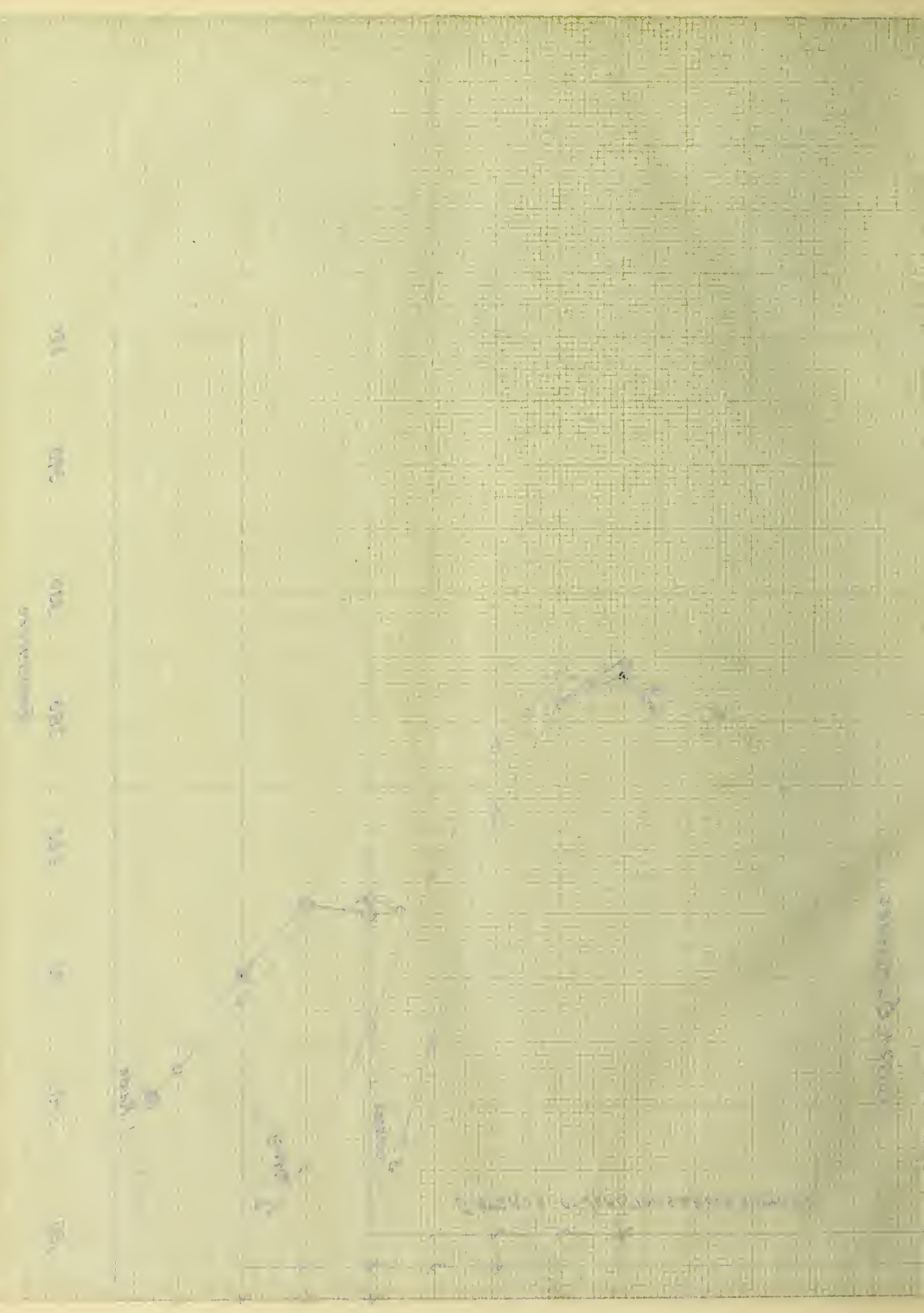


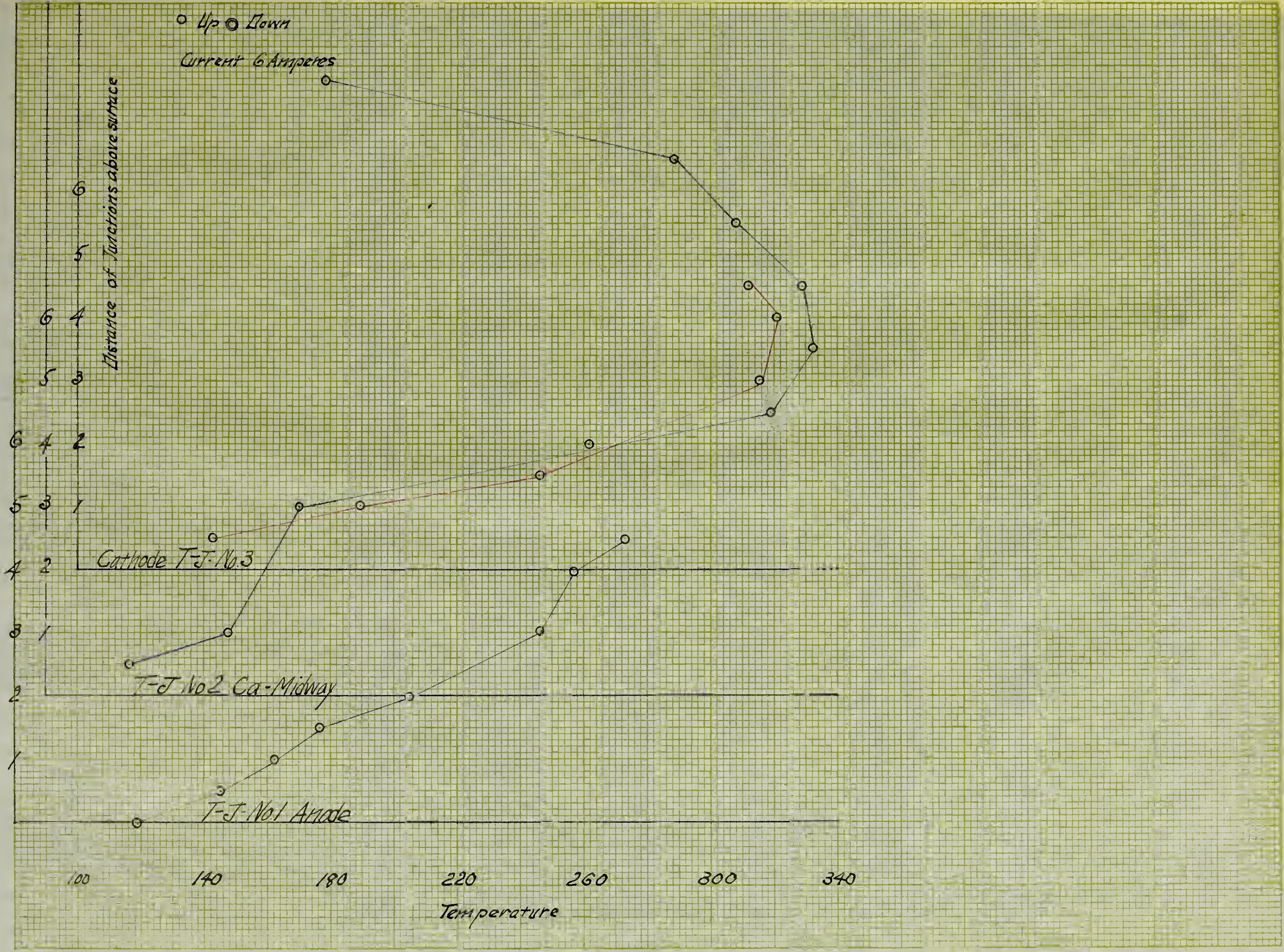

○ Up ◎ Down
Current constant at 4 amperes
Distance of Junctions above surface varied.
Distance
T-J No. 3 Cathode
T-J No. 1 Anode
T-J No. 2 Midway
100
140
180
220
260
300
340
Temperature
11
10
9
8
7
6
5
4
3
2
1



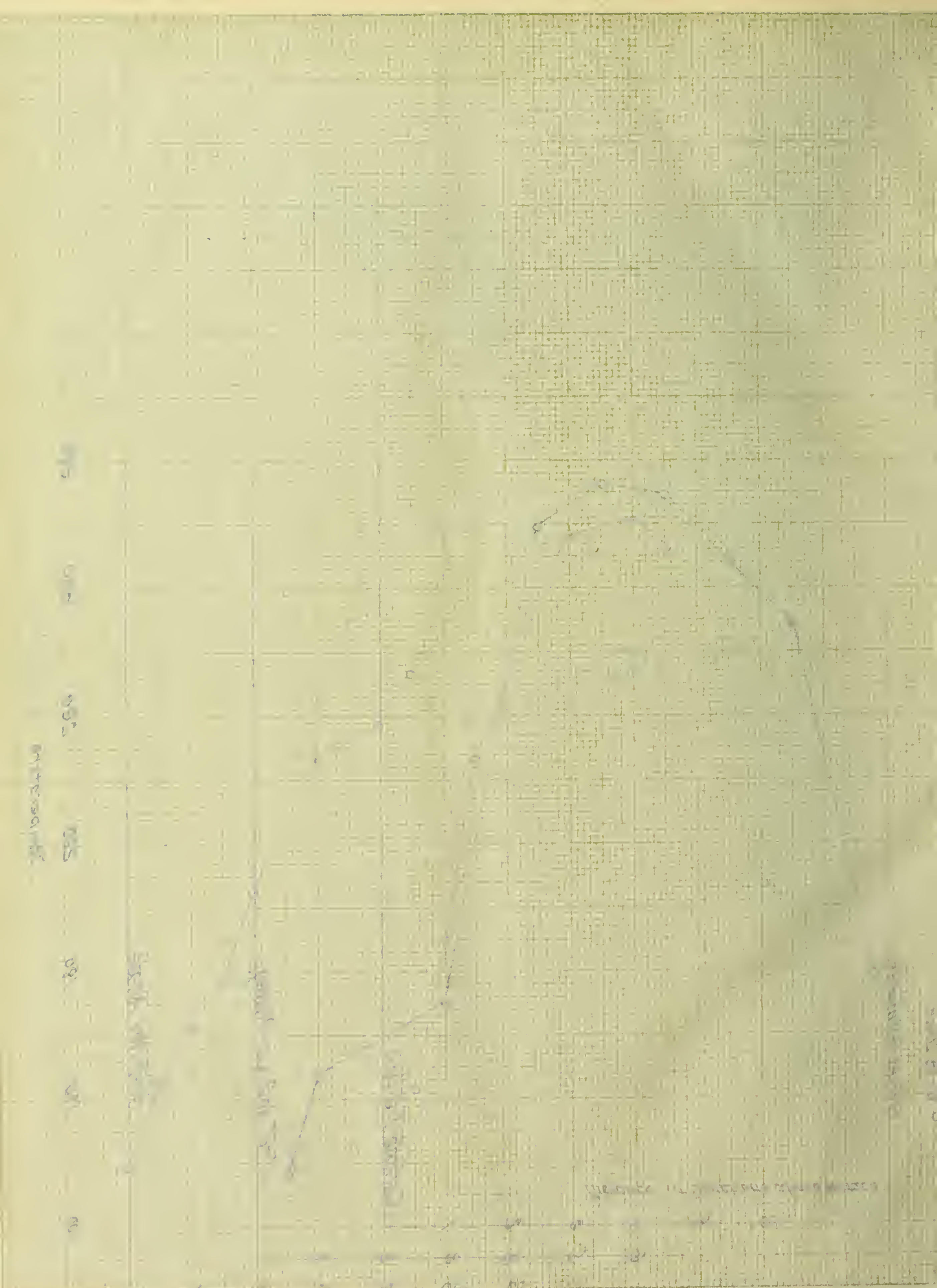


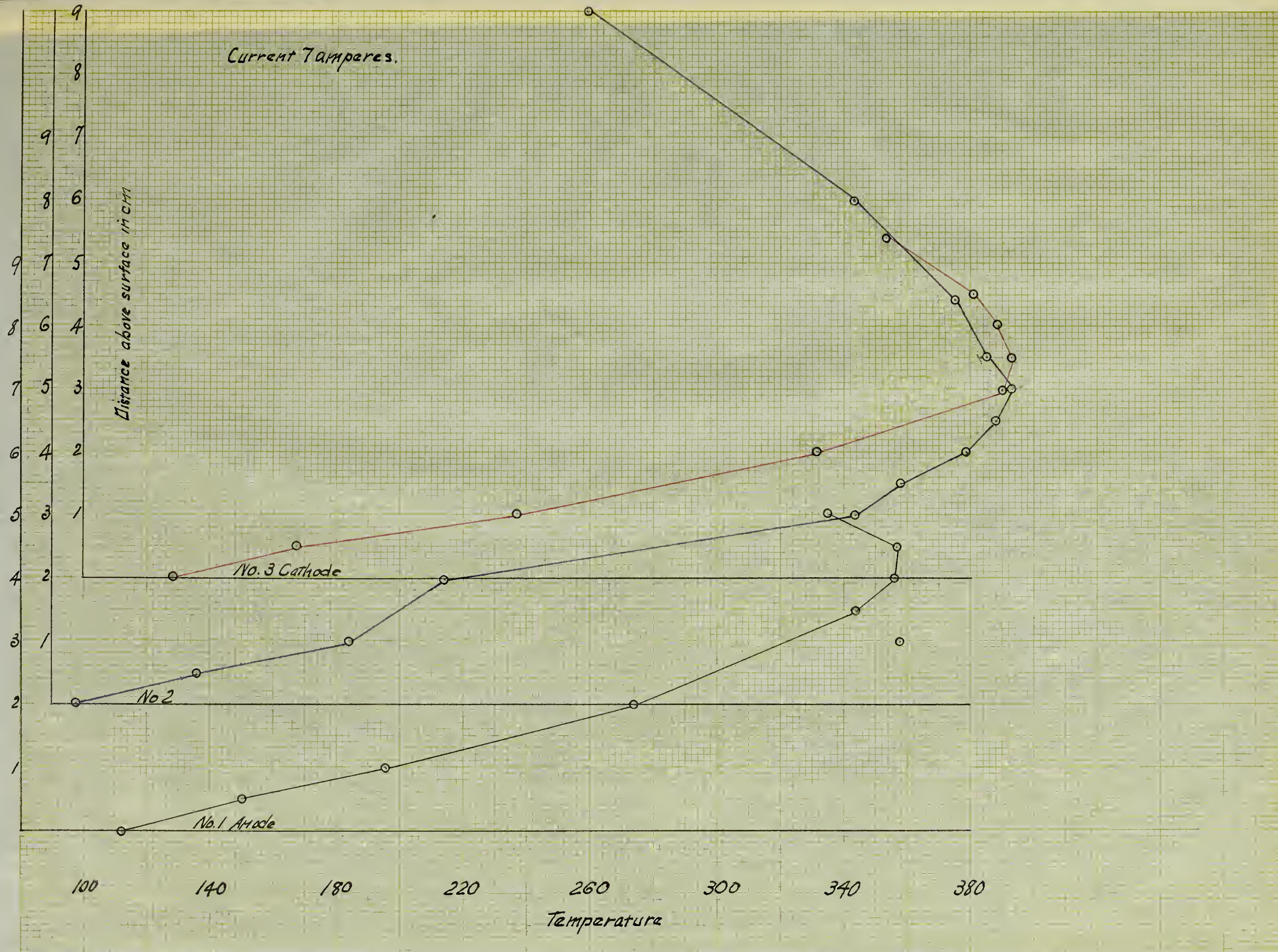
Up Down.
Current 5 amperes
Distance of Junctions above surface.
3 Cathode
2 Midway
1 Anode
4
3
2
1
100
140
180
220
260
300
340
380
Temperature.



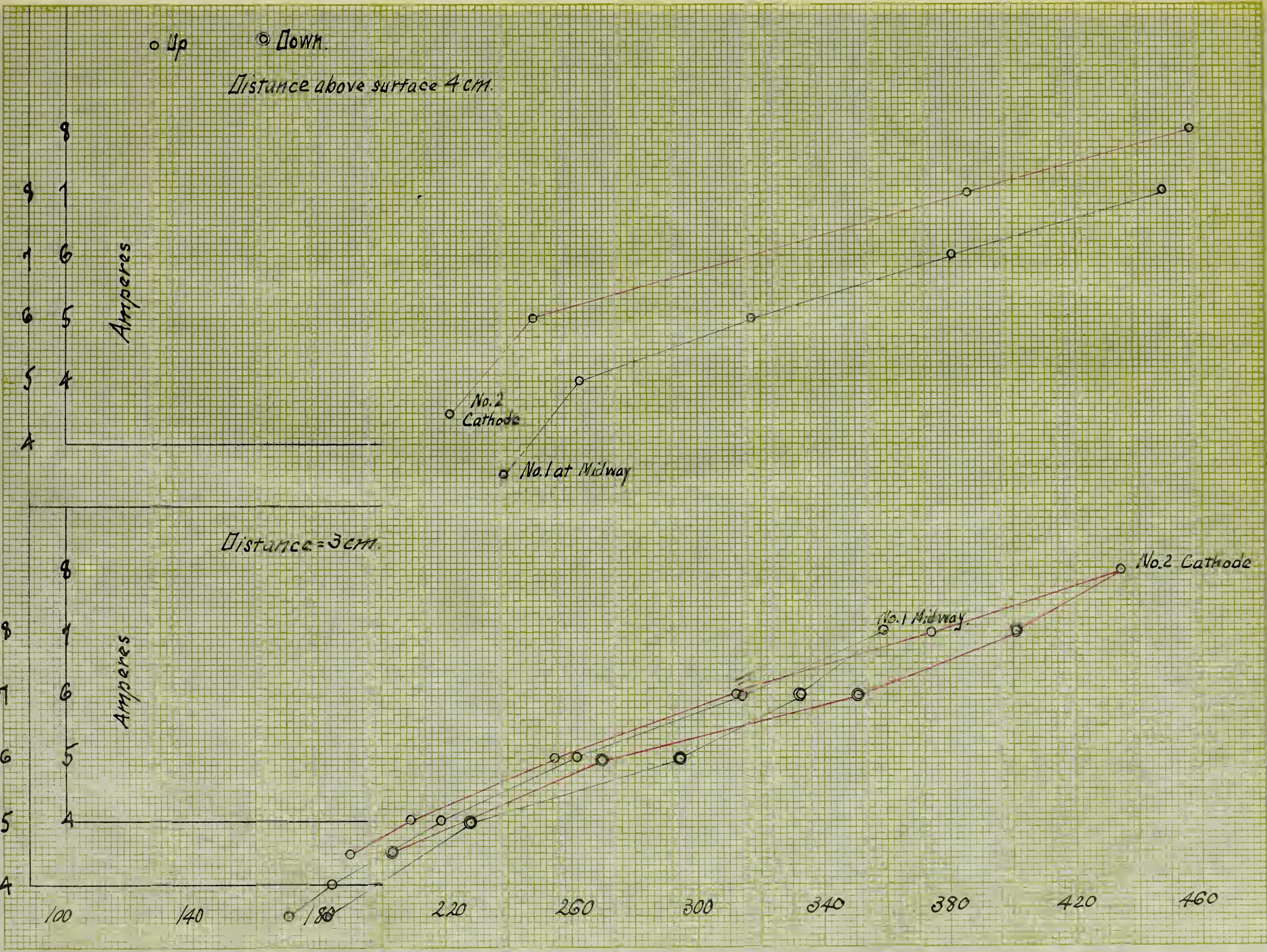


○ Up ◎ Down
Current 6 Amperes
Distance of Junctions above surface
Cathode T-J No.3
T-J No2 Ca-Midway
T-J No1 Anode
100
140
180
220
260
300
340
Temperature

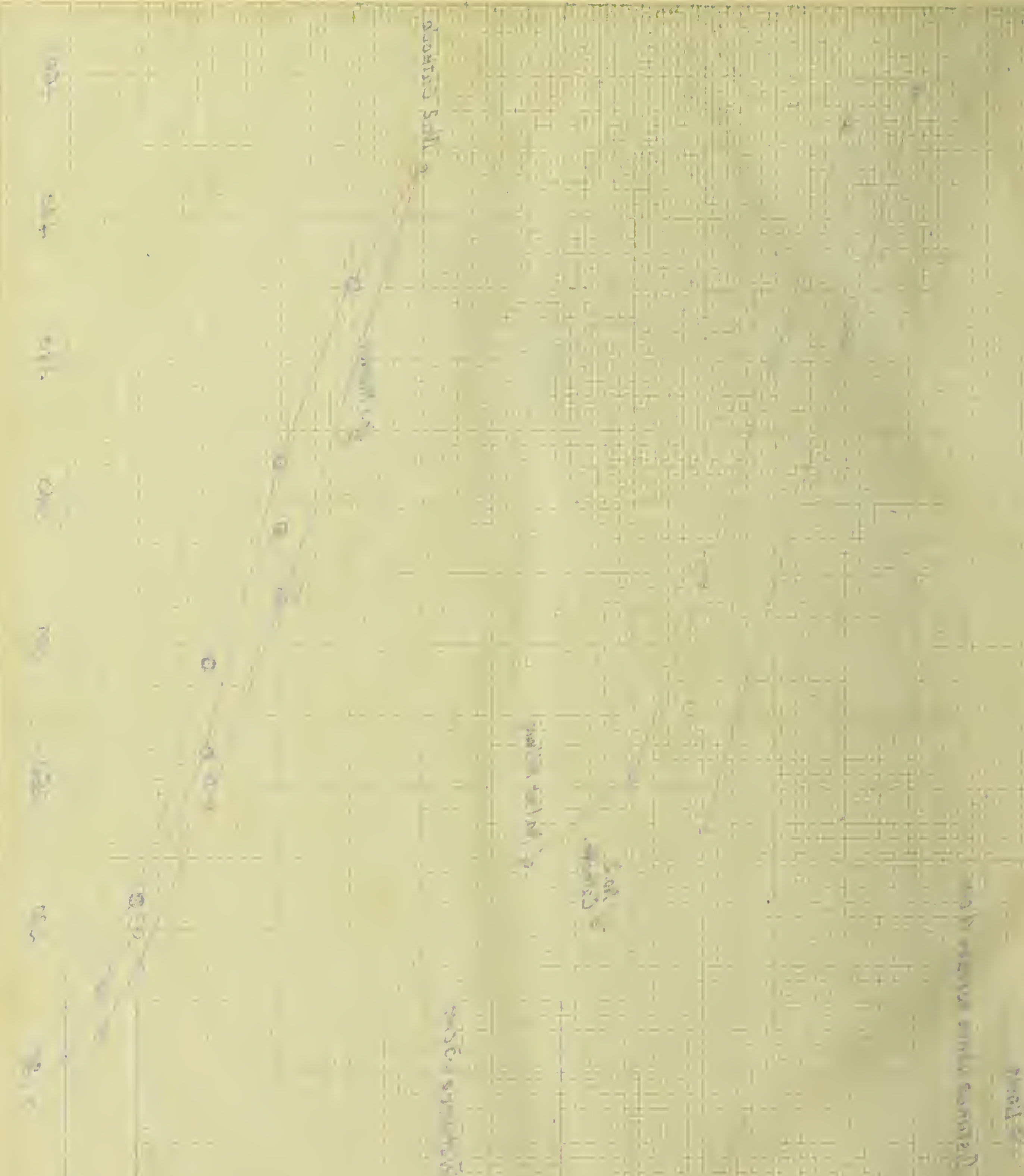


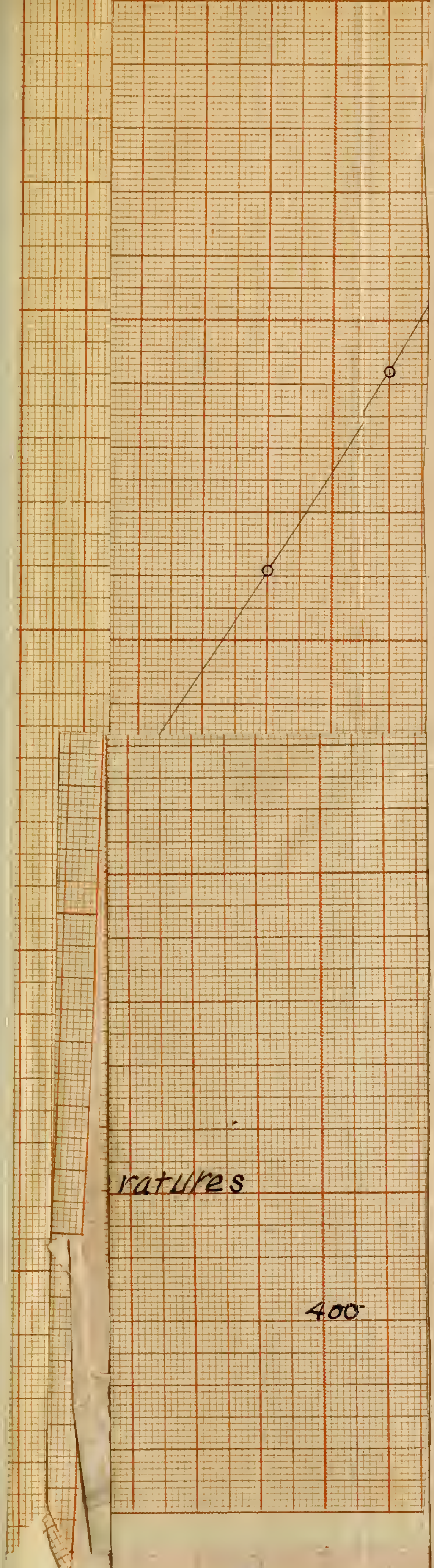


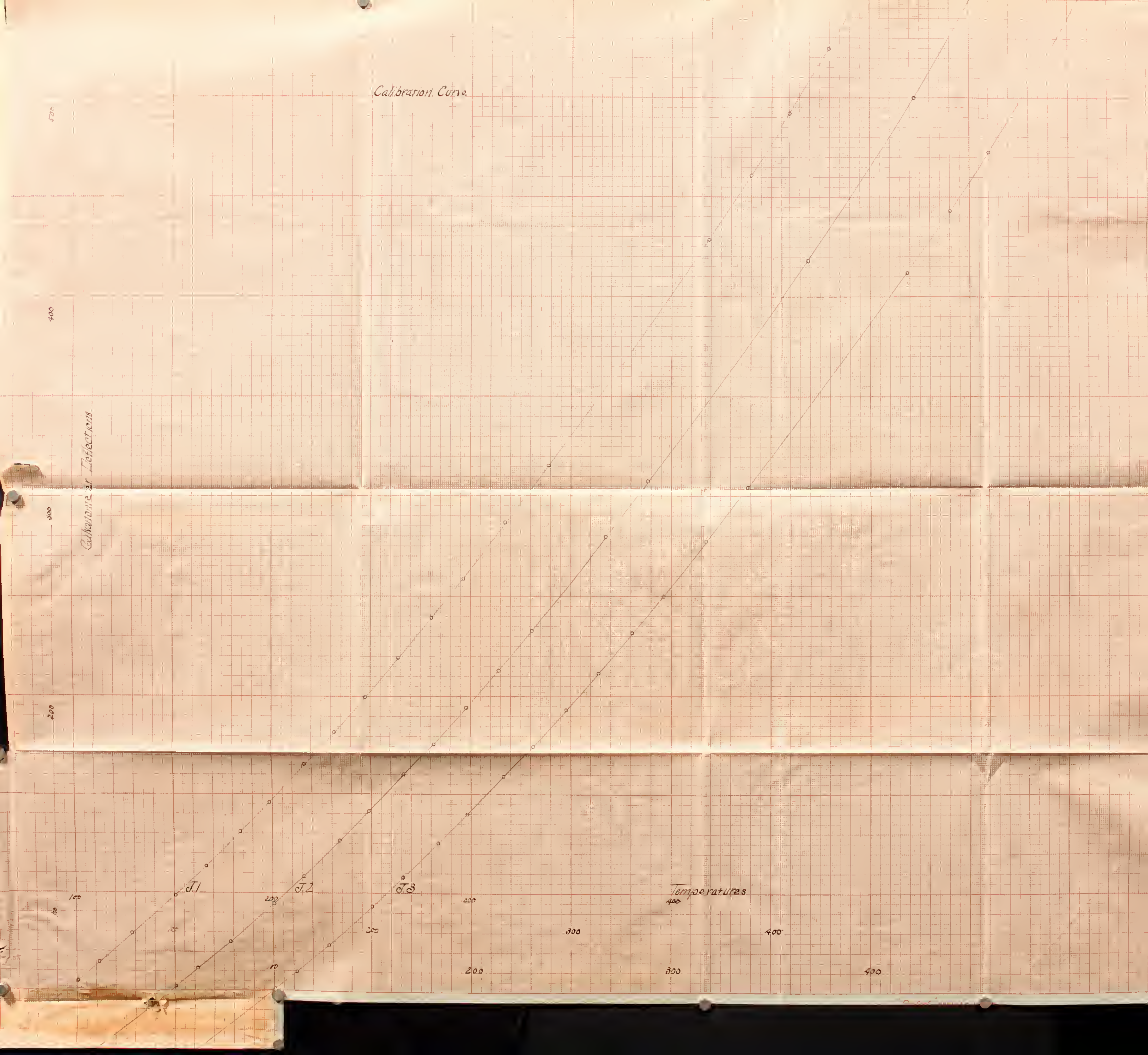
Current 7 amperes.
Distance above surface in cm
No. 3 Cathode
No 2
No. 1 Anode
100
140
180
220
260
300
340
380
Temperature



○ Up
◎ Down.
Distance above surface 4 cm.
Amperes
No.2 Cathode
No.1 at Midway
Distance = 3 cm.
Amperes
No.2 Cathode
No.1 Midway
100
140
180
220
260
300
340
380
420
460




ratures
400



Calibration Curve
Galvanometer Deflections
500
400
300
200
100
J.1
J.2
J.3
Temperatures
200
300
400
200
300
400
200
300
400